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Predictors of Situation Awareness in Graduate Student Registered Nurse Anesthetists

A dissertation submitted in partial fulfillment of the requirements for the degree of

Doctor of Philosophy at Virginia Commonwealth University

by

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Director: J. James Cotter, Ph.D.

Virginia Commonwealth University

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dedication and belief in me reaches far past anything I have dreamed for myself. Thank you for sharing these gifts with me.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

PREDICTORS OF SITUATION AWARENESS IN GRADUATE STUDENT REGISTERED NURSE ANESTHETISTS

Suzanne M. Wright, Ph.D.

A dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy at Virginia Commonwealth University.

Virginia Commonwealth University, 2009

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Situation awareness (SA) is defined as one's perception of the elements of the environment, the comprehension of their meaning, and the projection of their status in the near future. Stated more simply, SA is knowing what is going on around you. The concept of SA is well known in the field of aviation which is characterized by complexity and dynamism. The discipline of anesthesia shares these same characteristics, yet the study of SA in this setting is in its infancy.

Human error has been implicated in nearly 80% of all preventable medical errors. It is well documented that lack of SA frequently contributes to human error. Although the discipline of anesthesia has led the medical field in patient safety through rigorous study of human error and adverse events in the operating room, crises in anesthesia still exist. Nurse anesthetists should possess the ability to acquire and maintain SA at all

times during clinical situations in the operating room, yet there are no studies examining SA in this population.

Guided by Endsley's theory of situation awareness, the purpose of this study was to provide nurse anesthesia educators with a best evidence predictor model of SA in GSRNAs for curricular implementation. The study objectives are to determine: a) the extent to which memory, cognition, and automaticity are related to situation awareness, b) the extent to which any relationship amongst memory, cognition, and automaticity mediates their relationship with situation awareness, and c) the extent to which Endsley's theory of situation awareness is supported in the GSRNA population.

After IRB approval, 71 GSRNAs were randomly selected from each of three universities chosen for this study. A non-experimental, correlational design was used to measure the relationship between memory, cognition, and automaticity and SA. Situation awareness was measured by the WOMBAT-CS, a computer-based assessment tool for evaluating SA in complex-system operators such as pilots, air traffic controllers, and anesthetists. A stepwise multiple regression was performed between the GSRNA attributes and SA scores. Beta-weights were used to identify the magnitude each relationship.

Findings from this study revealed that cognition best predicts SA in the population of Graduate Student Registered Nurse Anesthetists, with the addition of memory and automaticity contributing no additional predictive value to the model. The results of this study have the potential to make a positive impact on the education and training of GSRNAs. Additionally, this study may provide foundational support for further research directed at assessing the effectiveness of high-fidelity simulated operating room environments in promoting SA in GSRNAs.

CHAPTER ONE: INTRODUCTION

Charles Jones was a fireman and the father of four children. One Saturday morning, he awoke to severe pain in his chest and found himself in the emergency department of a local hospital. Although his electrocardiogram revealed nothing unusual, his chest radiograph revealed an enlarged area of the aorta and a diagnosis of dissecting aortic aneurysm was made. Mr. Jones was admitted to the surgical intensive care unit where the vascular surgeon recommended an endovascular stent grafting of the weakened section of the aorta. A good prognosis was determined.

On the morning of surgery, Mr. Jones said 'good-bye' to his family and was taken to the operating room for the four-hour surgical procedure. Once in the operating room and prior to surgery, Mr. Jones was placed on his side to facilitate the placement of an epidural catheter by the anesthesia provider for post-operative pain control. Despite the use of local anesthetics at the epidural site, Mr. Jones complained of moderate discomfort in his back where the catheter was being placed.

At this point, the anesthesia provider directed the circulating nurse to give 100 micrograms of fentanyl, a very powerful narcotic analgesic, which was in a labeled syringe on top of the anesthesia cart. As the nurse administered the fentanyl, the anesthesia provider returned his attention to placing the epidural catheter. After a few moments, the patient became acutely distressed and stated he could not breathe; he soon became unresponsive. As the anesthesia provider attempted to rescue the patient, he glanced at the monitor and noted the patient's blood pressure to be 250/115 mmHg; a condition inconsistent with proper medical management of a dissecting aortic aneurysm. Mr. Jones' blood pressure then began to decline and his condition deteriorated rapidly. After 30 minutes of aggressive but unsuccessful resuscitation attempts, all efforts were ceased and Mr. Jones was pronounced dead in the operating room.

The autopsy described the cause of death as an aortic rupture likely due to severe high blood pressure. In an attempt to explain the circumstances surrounding this death, a root cause analysis was instituted. The information uncovered during this investigative process revealed that the circulating nurse did not give 100 micrograms of fentanyl, but rather picked up the wrong syringe and inadvertently administered 20 milligrams of a muscle paralytic to Mr. Jones. This simple human error of choosing and administering the wrong syringe of medication, led to a profound sympathetic nervous system response as Mr. Jones lie paralyzed, fully awake …… but unable to breathe, speak, or move.

Over the past two decades, particularly as our nation has moved toward a more consumer-driven health care system, there has been an increased awareness of and interest in patient safety and improved patient outcomes. In 1999, the National Academy of Sciences' Institute of Medicine report "To Err is Human: Building a Safer Health System" revealed a growing body of evidence substantiating medical error as a leading cause of death and injury in the United States (Kohn, Corrigan, & Donaldson, 1999). The report addresses the impact of human factors and organizational issues on errors and safety and estimates that up to 770,000 patients are injured and between 44,000 and 98,000 patients die each year from preventable medical errors. Medical errors cost our nation close to $38 billion each year; about $17 billion of those costs are associated with preventable human errors (Kohn, Corrigan, & Donaldson, 1999).

Background

Human Error in Medicine

Human factors is a broad term used to describe human performance and behavior, technology design, and human-environment interaction. The study of human factors deals with a myriad of human characteristics to include the psychological, social, and physical nature of human beings and the system(s) in which they function. Human characteristics leading to error in complex systems include fatigue, stress, unpreparedness, production pressure, and lack of situation awareness, just to name a few (Whittingham, 2004). When human factors are involved in outcomes less desirable than expected, such instances are considered to be caused by human error. Human error has long been studied in high-reliable organizations such as nuclear power, aviation, and the military (Reason, 1990; Perrow, 1999; Sheridan, 2003).

Since the early 1990's, there has been a concerted effort by scientists to study the impact human error plays in health care outcomes. Leape, Bates, and Cullen (1995) supported the development of a disciplined approach to safety in medicine by identifying and evaluating system failures which predisposed humans to make errors leading to adverse drug events. This study contributed to improvement in communication among health care providers by promoting the use of computerized physician order entry methods, a model which is ubiquitously employed today.

With the publication of the Institute of Medicine's seminal report "To Err is Human: Building a Safer Health System", the state of patient safety in North American at the end of the 20th century was examined (Kohn, Corrigan, & Donaldson, 1999). The report, highlighting a best evidence review of the literature on the potential for harm in modern medicine, explores and summarizes recommended changes necessary to prevent and mitigate the effects of injury to patients secondary to errors. This publication lead to the establishment of patient safety organizations (PSO's) which create a blame-free environment for reporting medical errors that may compromise quality of care and patient outcomes (Ilan & Fowler, 2005).

In the early 2000's, the Agency for Healthcare Research and Quality (AHRQ) commissioned the first evidence-based practice center with the purpose of critically reviewing scientific evidence surrounding practices relevant to improving patient safety and minimizing human error (Shojania, Duncan, & McDonald, 2001). These critical analyses were monumental in comprising a list of evidence-based practices for implementation in hospitals throughout the United States. Interestingly, this initiative spearheaded by AHRQ sparked interest in looking at human error and safety practices in industries outside of health care (Ilan & Fowler, 2005).

The patient safety movement has generated many promising efforts in improving quality and reducing error, but many agree there is still work to be done (Altman, Clancy, & Blendon, 2004). A culture of safety which includes the prevention of error, early detection of error, and minimizing the negative consequences of error is essential to improving quality and managing costs. Strong safety cultures thrive in industries where safety is an overarching goal, where problems are anticipated, and where training and education of workers is ongoing (Benhamou, Auroy, & Amalberti, 2007).

The Nature of Anesthesiology

The medical specialty of anesthesiology, along with emergency medicine and obstetrics, is characterized as one of the most complex and dynamic professions in health care (Gaba, Fish, & Howard, 1994). The delivery of anesthesia is filled with uncertainty and contingency and is therefore carried out with an onerous degree of inherent and undesirable risk. Factors leading to the disparate risk in this specialty include, but are not limited to, the anatomical and physiological variation of each individual patient, manipulation of the airway to ensure adequate ventilation and oxygenation, administration of rapidly-acting, potent, and potentially life-threatening medications, dependence on highly technical and complex monitoring devices and equipment, cannulation of major blood vessels, and management of the precipitous and adverse effects of surgery (Gaba, Fish & Howard, 1994).

Historically, the specialty of anesthesia has been beset with malpractice claims related to human error (Cheney, 1999). These claims included inadequate patient ventilation and oxygenation, medication errors, and inattention to the environment, to name a few (Gaba, Fish, & Howard, 1994). As a result, the anesthesia community rallied around this information and began to address these issues. The advent of innovative monitoring technologies in the 1980's, to include pulse oximetry and capnography, immensely decreased the occurrence of airway mismanagement by providing a sound mechanism for continuous assessment of ventilation and oxygenation. A call by the American Association of Nurse Anesthetists (AANA) and the American Society of Anesthesiologists (ASA), to remove offending, potentially lethal drugs, such as potassium chloride and insulin, from anesthesia carts in the operating room, greatly reduced the devastating consequences of their erroneous administration (US Pharmacopeia, 2000). Another example of the responsiveness of the anesthesia community within the last two decades is demonstrated in standards of practice drafted and adopted by the AANA and the ASA requiring that an anesthesia provider remains physically present in the operating room to continuously monitor the anesthetized patient at all times.

Anesthesia providers carry out a vast proportion of their work in the complex environment of the operating room, where keen awareness of each situation and a high level of vigilance throughout the peri-operative period are essential to assure positive patient outcomes. Operating rooms are error prone environments where opportunities for egregious mistakes are inherent due to high cognitive burdens and stress loads, high noise levels, demands on attention, and time pressures. Each day, anesthetists must assure the proper functioning of highly-technical equipment, perform a detailed pre-operative assessment on each patient, calculate and administer proper doses of potent medications, monitor the actions of other health care providers as they care for the same patient, perceive and understand individualized patient responses to medications and surgical interventions, troubleshoot often ambiguous patient conditions, make complex decisions under times of distress, and respond appropriately and accurately under production pressure.

Situation Awareness

Situation awareness is a construct dating back to World War I. Between 1910 and 1920, a reconnaissance flier named Manfred von Richthofen, perhaps better known as the Red Baron, gained notoriety for over 80 aerial combat victories. His success as a military jet fighter during the war was attributed to "good eyesight, the ability to shoot accurately, and an awareness of the tactical situation" (Blackburn, 2005, p. 45). Situation awareness was then, and is now, thought to be a critical skill for military pilots to achieve an adequate firing position and to survive the complex environment of combat, saturated with enemy aircraft (Endsley & Garland, 2000; Blackburn, 2005).

Situation awareness is demonstrated as one's ability to know what is going on in his or her environment at any given moment in time and is purported to be an essential skill in the successful management of complex systems where decisions must be made rapidly and under times of distress (Gaba & Howard, 1995; Endsley & Garland, 2000; Wright, Taekman, & Endsley, 2004; McIlvaine, 2007). Situation awareness refers to a requisite quality in operators of complex systems and is defined as their "perception of the elements of the environment, the comprehension of their meaning, and the projection of their status in the near future" (Endsley & Garland, 2000, p.5).

Despite recent quality improvements in the practice of anesthesia, situation awareness remains a key, but not completely understood, component of delivering safe and effective anesthesia care. The concept of situation awareness has been scrupulously studied in the fields of aviation, air traffic control, and the military (Kass, Herschler, & Companion, 1991; Jensen, 1997; O'Hare, 1997). These industries share equally with anesthesiology the characteristics of complexity and dynamism, yet the study of situation awareness in anesthesiology is in its infancy. To maximize human performance in complex domains such as aviation, the military, and health care, more research is needed to determine how one acquires situation awareness (Kogan, 2000).

Problem and Study Significance

The first organized program in nurse anesthesia education was formed in 1909 (Bankert, 1993). As of December 2008, there are nearly 110 nurse anesthesia educational programs working in concert with over 1800 clinical affiliates offering graduate level education to advanced practice nurses desiring entry to the anesthesia specialty (AANA, 2008). In 2007, over 2000 graduate student registered nurse anesthetists (GSRNAs) emerged from these institutions to join the ranks of the over 35,000 Certified Registered Nurse Anesthetists (CRNAs) in practice across the United States (AANA, 2008). Nurse anesthesia programs in the United States are charged with preparing graduates to successfully meet the challenges of providing safe and effective anesthesia care.

While the practice and delivery of anesthesia is generally safe, when complications do occur they can be catastrophic resulting in brain damage, paralysis, or even death. Due to the relevant infrequent occurrence of anesthesia-related crises, clinical rotations during training rarely offer opportunities for GSRNAs to manage and make critical decisions during the chaos and time constraints of an evolving emergency. Furthermore, most nurse anesthesia programs do not incorporate formalized didactic training targeted at anesthesia crisis management of which situation awareness is a key component (Yee et al., 2005). Instead, crisis management skills are assumed to naturally materialize through didactic coursework and during routine clinical rotations in the operating room. Nevertheless, CRNAs must be prepared to effectively manage crises that occur in practice.

Crisis management skills include effective communication, efficient use of resources, adoption of error prevention measures, the ability to know what is going on in the environment at all times, as well as the ability to forecast the outcomes of one's actions or inactions (Gaba, Fish & Howard, 1994; Perrow, 1999; Mitroff, 2001; Cannon-Bowers & Salas, 2006). Nurse anesthesia programs currently have no standardized method to screen, evaluate, or select candidates who possess good crisis management skills other than a highly subjective interview process. Findings from this study have the potential to positively influence the selection and training of GSRNAs. As individual attributes are found to be associated with situation awareness, nurse anesthesia educational programs can choose to develop curricula to cultivate and enhance these characteristics thereby potentially producing a safer and more adept practitioner. Additionally, this study may provide foundational support for research directed at assessing the effectiveness of high-fidelity simulated operating room environments in promoting situation awareness in GSRNAs.

Purpose of the Study

The purpose of this study is to provide nurse anesthesia educators with a best evidence predictor model of situation awareness in the GSRNA population. This study will examine situation awareness at the individual level by exploring the relationships between memory, cognition, and automaticity and situation awareness in this group. Situation awareness will serve as the criterion variable and will be measured by quantitative scores on the WOMBAT-CS Situation Awareness and Stress Tolerance Test.

Theoretical Framework

The underpinnings of this study lie in Endsley's (1995) theory of situation awareness. According to Endsley, situation awareness is a construct which describes the ability of operators of complex systems to be aware of salient elements in their environment. In order to master the operation of a complex system, an operator must have the ability to perceive elements occurring in the environment (Level 1), understand the importance of these elements (Level 2), and project the implications of future events (Level 3). Time plays an important role in the development of situation awareness because time, or lack thereof, can have a profound impact on the attainment of operator goals.

The theory of situation awareness proposes that anesthesia providers, as operators of and in complex systems, have the ability to perceive what is going on in the environment (1000cc of blood noted in the suction canister during surgery), understand what this means (the patient has less blood and hemoglobin circulating through his cardiovascular system), and project the implications of such an event (there is a decreased capacity to carry oxygen to vital organs which could lead to myocardial ischemia and cardiac death). The time it takes for the anesthesia provider to develop situation awareness is crucial as the human body, in the face of a physiologic insult such as profound blood loss, will not pause for the anesthetist's effective resolution of the crisis. The quality of a patient's outcome largely depends on the anesthesia provider's level of situation awareness.

In her work with aviators, Endsley identified that the constructs of memory, cognition, and automaticity all influence one's ability to develop situation awareness (Endsley & Garland, 2000). An exhaustive search of the literature databases MEDLINE/PubMed, Cumulative Index to Nursing and Allied Health Literature (CINAHL), and SCIRUS reveals no studies examining the relationship between memory, cognition, and/or automaticity and situation awareness in anesthesia providers, or more specifically, in GSRNAs.

Research Question

This study aims to answer the following research question: Is there a relationship between situation awareness and memory, cognition, and automaticity in graduate student registered nurse anesthetists?

Rationale and Significance

The development of a best evidence predictor model of situation awareness in GSRNAs has quality implications for anesthesia providers, nurse anesthesia educators, and the millions of patients who put their trust in the nation's health care system. Research focused on the enhancement of non-technical skills, such as situation awareness, has only recently become an area of interest in the specialty of anesthesia (Gaba et al., 1998, Fletcher et al., 2002, Fletcher, et al., 2003, Weller et al., 2003). Yee et al. (2005, p. 241) write,

> "traditional anesthesia teaching has placed significant emphasis on knowledge acquisition and the mastering of technical skills. However, critical incident reporting and observational studies, both in the clinical setting and on patient simulators, have identified non-technical skills to be major determinants of successful anesthesia crisis management. Non-technical skills are those that do not relate to medical knowledge or technical procedures but instead encompass cognitive skills (e.g., decision making, situation awareness) and interpersonal skills (e.g., exchanging information, assertiveness). These qualities are not necessarily acquired by anesthesia trainees through routine clinical experiences and may need to be specifically taught."

Given the importance of situation awareness in the provision of safe anesthesia care, the proposed study is justified because it will examine the contribution that individual attributes (memory, cognition, and automaticity) make to the acquisition of situation awareness. This work will test Endsley's theory of situation awareness in the GSRNA population.

Conclusion

The following paper is divided into four remaining chapters. Chapter Two provides a comprehensive literature review which analyzes the current body of knowledge related to situation awareness in complex systems, including anesthesiology. Endsley's theory of situation awareness is also presented and discussed. Chapter Three describes the proposed scientific methods and statistical analyses that will be used to answer the research question. Chapter Four will offer an objective and succinct presentation of the study results. Finally, Chapter Five will provide a summary and interpretation of the study results.

CHAPTER 2: LITERATURE REVIEW

According to The Joint Commission (2007), United States (US) hospitals continue to demonstrate steady improvements in health care quality and patient safety. These improvements have resulted in saved lives, better health, enhanced quality of life, and lower health care costs. Although this progress is encouraging, much room for improvement remains (The Joint Commission, 2007). The Joint Commission Sentinel Event database lists peri-operative complications among documented adverse events which lead to serious patient injury and death. Peri-operative human factors with a disposition to error are showcased in the database and include, for example, inadequate communication, incorrect assessment of a patient's physical condition, and inadequate orientation and training of health care professionals.

Health care in the US is the output of a large and complex system comprised of many interacting, interrelated, and interdependent parts. One discipline within the US health care system which is practiced within a similarly complex subsystem is anesthesiology. Just as our health care system is a complex arrangement in which <u>health care</u> is delivered, the practice of anesthesia is a complex arrangement in which anesthesia is delivered (Pott, Johnson, & Cnossen, 2005). An understanding of complex systems is necessary to realize the potential for human error in such dynamic environments.

Comprehension of the mechanisms of human error is important when the consequences of a failed complex system are potentially devastating.

In this chapter, the most current understanding of complex systems is provided as a foundation to examine the dynamic nature of anesthesia practice. A discussion of the opportunity for human error in anesthesia is offered to illuminate the consequences of error and to provide an understanding of how systems can potentially fail. An analysis of relevant literature establishing the essential linkage between the importance of situation awareness on the part of health care workers, including those in anesthesia, to complex systems is presented. An assessment of cognitive psychology literature reveals the relevance of situation awareness to anesthesia practice and how the lack of situation awareness may contribute to human error (Figure 1). Finally, the theory of situation awareness is described and scrutinized and studies which have employed the theory of situation awareness are evaluated.

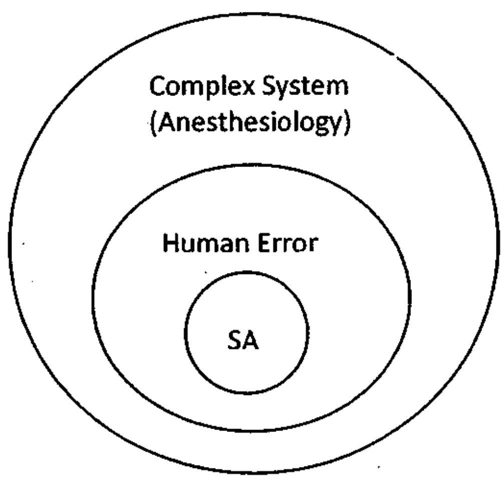

Figure 1: Schematic representation of the link between SA and anesthesiology.

Complex Systems

Complex systems are sometimes referred to as 'high-risk' systems. Industries such as aviation, nuclear science, military operations, and medicine have all been identified as high-risk operating systems (Gaba, 1994). Perrow (1999) characterizes complex systems as those with multiple levels of dynamic components which are non-linear, highly interactive, and tightly-coupled. Non-linearity describes the output or outcome of a system as more than the sum of each individual part and refers to the notion that components of a system may serve many purposes. Problems arising in a non-linear operating environment are difficult to solve and give rise to potential chaos (Khalil, 2001).

Petros (2003) discusses the profound influence non-linearity has on the practice of medicine. He argues that disciplines of medicine are not linear subjects and, in this context, "one and one do not always make two" (pg. 172). In one example, Petros (2003) describes how just a small medical intervention may spark a chain of events in the non-linear environment of the human body which may "profoundly disturb" its balance (p. 172). He posits that things in nature are complex and non-linear and have a propensity to self-organize to achieve homeostasis. Biological systems, therefore, are particularly vulnerable to chaos and disaster when the non-linearity of their control mechanisms are ignored during medical intervention and treatment (Petros, 2003).

In a between-subjects quasi-experimental design, Olsson, Enkvist, & Juslin (2006) studied analytical (rule-based) thinking vs. intuition (exemplar memory) in the performance of linear vs. non-linear tasks in 66 undergraduate students. The authors hypothesized that people are unable to use analytical processes in non-linear judgment tasks; to be successful they must shift to the use of exemplar memory or intuition. Although researchers were unable to support their hypothesis, they found a significant difference in performance between linear and non-linear tasks, with non-linear tasks being the most difficult to learn and most associated with poor performance.

High-level interactions inherent in complex systems are described as abstract, unfamiliar, unplanned, unexpected, invisible, and/or incomprehensible (Perrow, 1999). The nature of high-level interactions lends itself to the formation of unknown feedback mechanisms and a lack of redundancy often recognized as requisite characteristics of optimally functioning systems (Perrow, 1999). Orderly functioning of complex systems is dependent, in part, upon the operator's understanding of the dynamics of all components with which he or she interacts and the significance of all types of information produced by and within the system (Cannon-Bowers & Salas, 2006).

Coupling is defined as the association between an action and its consequences. Complex systems are characterized as having tightly-coupled parts, units, and sub-systems. The term tightly-coupled refers to a quality that prevents timely recovery from adverse events and leaves little to no room for error (Perrow, 1999). The degree of coupling in a system dictates complexity. Tightly-coupled systems demonstrate strict and invariant sequences, contain very little slack, and are not stagnant as they demand attention (Perrow, 1999). In computer science, for example, tight coupling describes a system in which hardware and software are not only linked together, but are also dependent upon each other.

Strauch (2004) describes complex systems as those that perform numerous tasks simultaneously and involve some human element. Complex system operators, acting as just one component of a system, often serve as monitors and high-level managers of an ever-increasing presence of automation. According to Strauch (2004), the human element is necessary to control the environment and obtain and interpret essential information to ensure the system's success. As technology and complexity of systems move forward, Strauch (2004) emphasizes the need for operators to perform at a higher cognitive and lower physical level.

The field of aviation has been identified as the epitome of a complex operating system, one of whose primary objective is passenger safety (Stanton, Chambers & Piggott, 2001; International Civil Aviation Organization, 2004; Ripley & Larkin, 2005). In congruence with Perrow's (1999) description of complex systems, nonlinearities are a feature of aircraft dynamics and flight control systems which require rapid response to achieve stability and performance (Sivasundarum, 2000). The pilot-automation interface describes a high-level interaction which is central to the development of advanced air traffic management (Callantine & Crane, 1999). Many facets of aviation are tightly-coupled whereas adverse incidents can quickly spiral out of control. Untoward consequences can rapidly ensue before operators are able to understand the situation and perform necessary corrective actions. In aviation, as well as in many other complex systems, trivial incidents can snowball in unpredictable ways and with possibly severe consequences.

Anesthesiology as a Complex System

Similar to aviation, anesthesia practice is a complex domain characterized by uncertainty, contingency, dynamism, high information load, risk, and non-linear sequences of activities at many levels (Gaba & Howard, 1995; Pott, Johnson & Cnossen, 2005; Runciman, Merry & Wolton, 2005). Anesthesia providers must effectively, efficiently, and simultaneously control and manage multiple, non-linear, high-level, and tightly-coupled components. These include rapidly-acting and potentially lethal medications, indirect measurements of critical vital signs, a chaotic operating room environment, highly technical equipment, invasive procedures, and the abstract nature of anesthesia and its effects on human anatomy and physiology.

In a 2006 study, Kumaraswami et al. queried anesthesia providers about the complexity of intra-operative events. The researchers found that patient positioning, endotracheal tube placement and verification, patient acuity, regional anesthesia, and central and peripheral intravenous line placement are among the most common factors contributing to the complexity of anesthesia. Anesthesia is determined to be a high-risk and complex practice in that every intervention is burdened with a plausible opportunity for patient injury (Gaba & Howard, 1994; Pott, Johnson, & Cnossen, 2005; Wright, 2006). In the anesthesia arena, effective performance requires expert knowledge, appropriate problem-solving skills, vigilance, and rapid responses to deteriorating conditions (Weinger & Slagle, 2002).

As technology becomes a more integral part of a system and the number of interdependencies grows between applications, complexity within the system further develops. The advent of state-of-the-art technology such as the Bispectral Index (BIS) monitor, computerized charting, and capnography, adds to the complexity of anesthesia practice. Barker (2003) believes the presence of advanced technology in operating rooms requires essential cognitive skills in the integration of copious amounts of data, in addition to requisite knowledge of pharmacology, physiology, and other operating room systems. For example, Weinger, Herndon, and Gaba (1997) found that the use of transesophageal echocardiography by anesthesia providers during coronary artery bypass graft surgery may adversely affect clinical vigilance and workload distribution. Because the difference between a trivial event and an adverse event in anesthesia often rests on the anesthesia provider's shoulders, the addition of technology to the operating room landscape adds further burden and potentially, an additional layer of complexity.

The management of a myriad of monitoring equipment and anesthesia machines is becoming increasingly complex. Doyle (2001) found many subtle complexities related to the operation of a specific brand of a newly-introduced anesthesia machine. Special challenges related to this particular machine include software design flaws that rendered the machine error-prone if the machine is checked with a popular anesthetic vaporizer in place. Other problematic features of this particular anesthesia machine include an oxygen flow default that is set to the "off" position upon completion of the machine check, a delay in ventilator function once the ventilator is switched to the "on" position, virtual (digital) versus real (mechanical) gas flowmeters, and unreliable capnography data. It is not unusual to see up to five or more different types of anesthesia machines, each with their own idiosyncrasies, throughout the operating rooms of one hospital system for which anesthesia providers are responsible. It is recommended that anesthesia providers have a thorough understanding of the operations of each type of anesthesia machine they may potentially use (Manley & Cuddeford, 1996; Eisenkraft, 2005; American Association of Nurse Anesthetists, 2007).

Just as Perrow (1999) describes high-risk environments as those that are complex and tightly coupled, Gaba, Fish and Howard (1994) describe anesthesia as complex and tightly-coupled. At the individual level, patients are very complex with tightly-coupled anatomical and physiological systems. For example, rarely will pathology cripple the respiratory system without an adverse influence on the cardiovascular system. Proper functioning of the cardiovascular system will not sustain itself without quick attention to the respiratory insult. Additionally, many physiological functions of the human body are non-linear: independently, the lungs and the heart are incapable of sustaining life. On a systems level, operating room teams are similarly complex and tightly-coupled. For example, should a surgeon inadvertently rupture a main artery during the course of surgery, major loss of blood would result. A delayed response on the part of the anesthetist to adjust for the blood loss in this instance can contribute to adverse consequences in the form of poor patient outcomes (Gaba, Fish & Howard, 1994). In the operating room environment, actions or inactions of just one team member can swiftly and very powerfully influence other parts of the system.

All of the aforementioned factors associated with anesthesia practice conflate to cause information overload which, in turn, adds to its complex nature. The anesthesia provider is responsible for perceiving and comprehending an inordinate amount of sensory input in a fast-paced environment, rich with distractions. Endsley & Garland (2000) proclaim that more data, a by-product of more technology and monitoring systems, does not necessarily mean more meaningful information. These researchers agree that complex systems produce so much data, that it is often difficult to find "what is needed, when it is needed", leaving operators inadequately informed and cognitively and physically handicapped as they attempt to manage the complexity of their environment (p. 4).

Anesthesia services are provided within a dynamic socio-technical system that has the capability of reaching a number of different states of complexity (Pott, Johnson, & Cnossen, 2005). Similar to other complex operating environments, the practice and delivery of anesthesia is characterized has having non-linear, highly-interactive, and tightly-coupled components. Anesthesia providers, as operators in this complex domain, are not immune to human error and must have a thorough understanding of salient elements in their environment as well as possess the requisite skills to function effectively.

Human Error in Complex Systems

Any complex system harbors a proneness to error given the interaction among people, materials, machines, facilities, and procedures (Chapanis, 1996; Perrow, 1999). The study of human error in complex systems such as aviation, nuclear power, military operations, and medicine remains fertile ground for improving quality and enhancing the safety of all stakeholders.

The cognitive study of human error is a vast field borne as a development of human factors engineering which is concerned with improving performance and enhancing safety in the human-environment relationship (Reason, 1990). Although numerous theories and frameworks are associated with the study of human error, two well-recognized and prominent human error researchers, Reason (1990) and Rasmussen (2003), have developed theories particularly appropriate for the study of human error in the anesthesia environment.

Reason's Swiss Cheese Model

The Swiss Cheese Model of human error describes the opportunity for error as a product of active failures and latent factors embedded in a system's defense mechanisms (Reason, 2000). In this model, the slices of Swiss cheese symbolize system defense mechanisms where active failures and latent factors are represented as holes in the slices of cheese. When the holes in each slice of Swiss cheese come into proper alignment, a course for error is created (Figure 2). According to Reason (2000), an active failure is defined as any unsafe act perpetrated by persons in contact with the system. These are more commonly referred to as slips, lapses, and mistakes. Latent factors are described as dormant mechanisms living within a system that create an accident opportunity only when they come in contact with active failures. Latent factors include those caused by realities such as production pressure, scheduling difficulties, insufficient equipment, fatigue, and improper training.

Reason's (1990) model of human error has become the dominant paradigm for analyzing errors in complex systems (Perneger, 2005). The Swiss Cheese Model does

Predictors of Situation Awareness in Graduate Student Registered Nurse Anesthetists

A dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy at Virginia Commonwealth University

by

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

PREDICTORS OF SITUATION AWARENESS IN GRADUATE STUDENT REGISTERED NURSE ANESTHETISTS

Suzanne M. Wright, Ph.D.

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Situation awareness (SA) is defined as one's perception of the elements of the environment, the comprehension of their meaning, and the projection of their status in the near future. Stated more simply, SA is knowing what is going on around you. The concept of SA is well known in the field of aviation which is characterized by complexity and dynamism. The discipline of anesthesia shares these same characteristics, yet the study of SA in this setting is in its infancy.

Human error has been implicated in nearly 80% of all preventable medical errors. It is well documented that lack of SA frequently contributes to human error. Although the discipline of anesthesia has led the medical field in patient safety through rigorous study of human error and adverse events in the operating room, crises in anesthesia still exist. Nurse anesthetists should possess the ability to acquire and maintain SA at all

times during clinical situations in the operating room, yet there are no studies examining SA in this population.

Guided by Endsley's theory of situation awareness, the purpose of this study was to provide nurse anesthesia educators with a best evidence predictor model of SA in GSRNAs for curricular implementation. The study objectives are to determine: a) the extent to which memory, cognition, and automaticity are related to situation awareness, b) the extent to which any relationship amongst memory, cognition, and automaticity mediates their relationship with situation awareness, and c) the extent to which Endsley's theory of situation awareness is supported in the GSRNA population.

After IRB approval, 71 GSRNAs were randomly selected from each of three universities chosen for this study. A non-experimental, correlational design was used to measure the relationship between memory, cognition, and automaticity and SA. Situation awareness was measured by the WOMBAT-CS, a computer-based assessment tool for evaluating SA in complex-system operators such as pilots, air traffic controllers, and anesthetists. A stepwise multiple regression was performed between the GSRNA attributes and SA scores. Beta-weights were used to identify the magnitude each relationship.

Findings from this study revealed that cognition best predicts SA in the population of Graduate Student Registered Nurse Anesthetists, with the addition of memory and automaticity contributing no additional predictive value to the model. The results of this study have the potential to make a positive impact on the education and training of GSRNAs. Additionally, this study may provide foundational support for further research directed at assessing the effectiveness of high-fidelity simulated operating room environments in promoting SA in GSRNAs.

CHAPTER ONE: INTRODUCTION

Charles Jones was a fireman and the father of four children. One Saturday morning, he awoke to severe pain in his chest and found himself in the emergency department of a local hospital. Although his electrocardiogram revealed nothing unusual, his chest radiograph revealed an enlarged area of the aorta and a diagnosis of dissecting aortic aneurysm was made. Mr. Jones was admitted to the surgical intensive care unit where the vascular surgeon recommended an endovascular stent grafting of the weakened section of the aorta. A good prognosis was determined.

On the morning of surgery, Mr. Jones said 'good-bye' to his family and was taken to the operating room for the four-hour surgical procedure. Once in the operating room and prior to surgery, Mr. Jones was placed on his side to facilitate the placement of an epidural catheter by the anesthesia provider for post-operative pain control. Despite the use of local anesthetics at the epidural site, Mr. Jones complained of moderate discomfort in his back where the catheter was being placed.

At this point, the anesthesia provider directed the circulating nurse to give 100 micrograms of fentanyl, a very powerful narcotic analgesic, which was in a labeled syringe on top of the anesthesia cart. As the nurse administered the fentanyl, the anesthesia provider returned his attention to placing the epidural catheter. After a few moments, the patient became acutely distressed and stated he could not breathe; he soon became unresponsive. As the anesthesia provider attempted to rescue the patient, he glanced at the monitor and noted the patient's blood pressure to be 250/115 mmHg; a condition inconsistent with proper medical management of a dissecting aortic aneurysm. Mr. Jones' blood pressure then began to decline and his condition deteriorated rapidly. After 30 minutes of aggressive but unsuccessful resuscitation attempts, all efforts were ceased and Mr. Jones was pronounced dead in the operating room.

The autopsy described the cause of death as an aortic rupture likely due to severe high blood pressure. In an attempt to explain the circumstances surrounding this death, a root cause analysis was instituted. The information uncovered during this investigative process revealed that the circulating nurse did not give 100 micrograms of fentanyl, but rather picked up the wrong syringe and inadvertently administered 20 milligrams of a muscle paralytic to Mr. Jones. This simple human error of choosing and administering the wrong syringe of medication, led to a profound sympathetic nervous system response as Mr. Jones lie paralyzed, fully awake …… but unable to breathe, speak, or move.

Over the past two decades, particularly as our nation has moved toward a more consumer-driven health care system, there has been an increased awareness of and interest in patient safety and improved patient outcomes. In 1999, the National Academy of Sciences' Institute of Medicine report "To Err is Human: Building a Safer Health System" revealed a growing body of evidence substantiating medical error as a leading cause of death and injury in the United States (Kohn, Corrigan, & Donaldson, 1999). The report addresses the impact of human factors and organizational issues on errors and safety and estimates that up to 770,000 patients are injured and between 44,000 and 98,000 patients die each year from preventable medical errors. Medical errors cost our nation close to $38 billion each year; about $17 billion of those costs are associated with preventable human errors (Kohn, Corrigan, & Donaldson, 1999).

Background

Human Error in Medicine

Human factors is a broad term used to describe human performance and behavior, technology design, and human-environment interaction. The study of human factors deals with a myriad of human characteristics to include the psychological, social, and physical nature of human beings and the system(s) in which they function. Human characteristics leading to error in complex systems include fatigue, stress, unpreparedness, production pressure, and lack of situation awareness, just to name a few (Whittingham, 2004). When human factors are involved in outcomes less desirable than expected, such instances are considered to be caused by human error. Human error has long been studied in high-reliable organizations such as nuclear power, aviation, and the military (Reason, 1990; Perrow, 1999; Sheridan, 2003).

Since the early 1990's, there has been a concerted effort by scientists to study the impact human error plays in health care outcomes. Leape, Bates, and Cullen (1995) supported the development of a disciplined approach to safety in medicine by identifying and evaluating system failures which predisposed humans to make errors leading to adverse drug events. This study contributed to improvement in communication among health care providers by promoting the use of computerized physician order entry methods, a model which is ubiquitously employed today.

With the publication of the Institute of Medicine's seminal report "To Err is Human: Building a Safer Health System", the state of patient safety in North American at the end of the 20th century was examined (Kohn, Corrigan, & Donaldson, 1999). The report, highlighting a best evidence review of the literature on the potential for harm in modern medicine, explores and summarizes recommended changes necessary to prevent and mitigate the effects of injury to patients secondary to errors. This publication lead to the establishment of patient safety organizations (PSO's) which create a blame-free environment for reporting medical errors that may compromise quality of care and patient outcomes (Ilan & Fowler, 2005).

In the early 2000's, the Agency for Healthcare Research and Quality (AHRQ) commissioned the first evidence-based practice center with the purpose of critically reviewing scientific evidence surrounding practices relevant to improving patient safety and minimizing human error (Shojania, Duncan, & McDonald, 2001). These critical analyses were monumental in comprising a list of evidence-based practices for implementation in hospitals throughout the United States. Interestingly, this initiative spearheaded by AHRQ sparked interest in looking at human error and safety practices in industries outside of health care (Ilan & Fowler, 2005).

The patient safety movement has generated many promising efforts in improving quality and reducing error, but many agree there is still work to be done (Altman, Clancy, & Blendon, 2004). A culture of safety which includes the prevention of error, early detection of error, and minimizing the negative consequences of error is essential to improving quality and managing costs. Strong safety cultures thrive in industries where safety is an overarching goal, where problems are anticipated, and where training and education of workers is ongoing (Benhamou, Auroy, & Amalberti, 2007).

The Nature of Anesthesiology

The medical specialty of anesthesiology, along with emergency medicine and obstetrics, is characterized as one of the most complex and dynamic professions in health care (Gaba, Fish, & Howard, 1994). The delivery of anesthesia is filled with uncertainty and contingency and is therefore carried out with an onerous degree of inherent and undesirable risk. Factors leading to the disparate risk in this specialty include, but are not limited to, the anatomical and physiological variation of each individual patient, manipulation of the airway to ensure adequate ventilation and oxygenation, administration of rapidly-acting, potent, and potentially life-threatening medications, dependence on highly technical and complex monitoring devices and equipment, cannulation of major blood vessels, and management of the precipitous and adverse effects of surgery (Gaba, Fish & Howard, 1994).

Historically, the specialty of anesthesia has been beset with malpractice claims related to human error (Cheney, 1999). These claims included inadequate patient ventilation and oxygenation, medication errors, and inattention to the environment, to name a few (Gaba, Fish, & Howard, 1994). As a result, the anesthesia community rallied around this information and began to address these issues. The advent of innovative monitoring technologies in the 1980's, to include pulse oximetry and capnography, immensely decreased the occurrence of airway mismanagement by providing a sound mechanism for continuous assessment of ventilation and oxygenation. A call by the American Association of Nurse Anesthetists (AANA) and the American Society of Anesthesiologists (ASA), to remove offending, potentially lethal drugs, such as potassium chloride and insulin, from anesthesia carts in the operating room, greatly reduced the devastating consequences of their erroneous administration (US Pharmacopeia, 2000). Another example of the responsiveness of the anesthesia community within the last two decades is demonstrated in standards of practice drafted and adopted by the AANA and the ASA requiring that an anesthesia provider remains physically present in the operating room to continuously monitor the anesthetized patient at all times.

Anesthesia providers carry out a vast proportion of their work in the complex environment of the operating room, where keen awareness of each situation and a high level of vigilance throughout the peri-operative period are essential to assure positive patient outcomes. Operating rooms are error prone environments where opportunities for egregious mistakes are inherent due to high cognitive burdens and stress loads, high noise levels, demands on attention, and time pressures. Each day, anesthetists must assure the proper functioning of highly-technical equipment, perform a detailed pre-operative assessment on each patient, calculate and administer proper doses of potent medications, monitor the actions of other health care providers as they care for the same patient, perceive and understand individualized patient responses to medications and surgical interventions, troubleshoot often ambiguous patient conditions, make complex decisions under times of distress, and respond appropriately and accurately under production pressure.

Situation Awareness

Situation awareness is a construct dating back to World War I. Between 1910 and 1920, a reconnaissance flier named Manfred von Richthofen, perhaps better known as the Red Baron, gained notoriety for over 80 aerial combat victories. His success as a military jet fighter during the war was attributed to "good eyesight, the ability to shoot accurately, and an awareness of the tactical situation" (Blackburn, 2005, p. 45). Situation awareness was then, and is now, thought to be a critical skill for military pilots to achieve an adequate firing position and to survive the complex environment of combat, saturated with enemy aircraft (Endsley & Garland, 2000; Blackburn, 2005).

Situation awareness is demonstrated as one's ability to know what is going on in his or her environment at any given moment in time and is purported to be an essential skill in the successful management of complex systems where decisions must be made rapidly and under times of distress (Gaba & Howard, 1995; Endsley & Garland, 2000; Wright, Taekman, & Endsley, 2004; McIlvaine, 2007). Situation awareness refers to a requisite quality in operators of complex systems and is defined as their "perception of the elements of the environment, the comprehension of their meaning, and the projection of their status in the near future" (Endsley & Garland, 2000, p.5).

Despite recent quality improvements in the practice of anesthesia, situation awareness remains a key, but not completely understood, component of delivering safe and effective anesthesia care. The concept of situation awareness has been scrupulously studied in the fields of aviation, air traffic control, and the military (Kass, Herschler, & Companion, 1991; Jensen, 1997; O'Hare, 1997). These industries share equally with anesthesiology the characteristics of complexity and dynamism, yet the study of situation awareness in anesthesiology is in its infancy. To maximize human performance in complex domains such as aviation, the military, and health care, more research is needed to determine how one acquires situation awareness (Kogan, 2000).

Problem and Study Significance

The first organized program in nurse anesthesia education was formed in 1909 (Bankert, 1993). As of December 2008, there are nearly 110 nurse anesthesia educational programs working in concert with over 1800 clinical affiliates offering graduate level education to advanced practice nurses desiring entry to the anesthesia specialty (AANA, 2008). In 2007, over 2000 graduate student registered nurse anesthetists (GSRNAs) emerged from these institutions to join the ranks of the over 35,000 Certified Registered Nurse Anesthetists (CRNAs) in practice across the United States (AANA, 2008). Nurse anesthesia programs in the United States are charged with preparing graduates to successfully meet the challenges of providing safe and effective anesthesia care.

While the practice and delivery of anesthesia is generally safe, when complications do occur they can be catastrophic resulting in brain damage, paralysis, or even death. Due to the relevant infrequent occurrence of anesthesia-related crises, clinical rotations during training rarely offer opportunities for GSRNAs to manage and make critical decisions during the chaos and time constraints of an evolving emergency. Furthermore, most nurse anesthesia programs do not incorporate formalized didactic training targeted at anesthesia crisis management of which situation awareness is a key component (Yee et al., 2005). Instead, crisis management skills are assumed to naturally materialize through didactic coursework and during routine clinical rotations in the operating room. Nevertheless, CRNAs must be prepared to effectively manage crises that occur in practice.

Crisis management skills include effective communication, efficient use of resources, adoption of error prevention measures, the ability to know what is going on in the environment at all times, as well as the ability to forecast the outcomes of one's actions or inactions (Gaba, Fish & Howard, 1994; Perrow, 1999; Mitroff, 2001; Cannon-Bowers & Salas, 2006). Nurse anesthesia programs currently have no standardized method to screen, evaluate, or select candidates who possess good crisis management skills other than a highly subjective interview process. Findings from this study have the potential to positively influence the selection and training of GSRNAs. As individual attributes are found to be associated with situation awareness, nurse anesthesia educational programs can choose to develop curricula to cultivate and enhance these characteristics thereby potentially producing a safer and more adept practitioner. Additionally, this study may provide foundational support for research directed at assessing the effectiveness of high-fidelity simulated operating room environments in promoting situation awareness in GSRNAs.

Purpose of the Study

The purpose of this study is to provide nurse anesthesia educators with a best evidence predictor model of situation awareness in the GSRNA population. This study will examine situation awareness at the individual level by exploring the relationships between memory, cognition, and automaticity and situation awareness in this group. Situation awareness will serve as the criterion variable and will be measured by quantitative scores on the WOMBAT-CS Situation Awareness and Stress Tolerance Test.

Theoretical Framework

The underpinnings of this study lie in Endsley's (1995) theory of situation awareness. According to Endsley, situation awareness is a construct which describes the ability of operators of complex systems to be aware of salient elements in their environment. In order to master the operation of a complex system, an operator must have the ability to perceive elements occurring in the environment (Level 1), understand the importance of these elements (Level 2), and project the implications of future events (Level 3). Time plays an important role in the development of situation awareness because time, or lack thereof, can have a profound impact on the attainment of operator goals.

The theory of situation awareness proposes that anesthesia providers, as operators of and in complex systems, have the ability to perceive what is going on in the environment (1000cc of blood noted in the suction canister during surgery), understand what this means (the patient has less blood and hemoglobin circulating through his cardiovascular system), and project the implications of such an event (there is a decreased capacity to carry oxygen to vital organs which could lead to myocardial ischemia and cardiac death). The time it takes for the anesthesia provider to develop situation awareness is crucial as the human body, in the face of a physiologic insult such as profound blood loss, will not pause for the anesthetist's effective resolution of the crisis. The quality of a patient's outcome largely depends on the anesthesia provider's level of situation awareness.

In her work with aviators, Endsley identified that the constructs of memory, cognition, and automaticity all influence one's ability to develop situation awareness (Endsley & Garland, 2000). An exhaustive search of the literature databases MEDLINE/PubMed, Cumulative Index to Nursing and Allied Health Literature (CINAHL), and SCIRUS reveals no studies examining the relationship between memory, cognition, and/or automaticity and situation awareness in anesthesia providers, or more specifically, in GSRNAs.

Research Question

This study aims to answer the following research question: Is there a relationship between situation awareness and memory, cognition, and automaticity in graduate student registered nurse anesthetists?

Rationale and Significance

The development of a best evidence predictor model of situation awareness in GSRNAs has quality implications for anesthesia providers, nurse anesthesia educators, and the millions of patients who put their trust in the nation's health care system. Research focused on the enhancement of non-technical skills, such as situation awareness, has only recently become an area of interest in the specialty of anesthesia (Gaba et al., 1998, Fletcher et al., 2002, Fletcher, et al., 2003, Weller et al., 2003). Yee et al. (2005, p. 241) write,

> "traditional anesthesia teaching has placed significant emphasis on knowledge acquisition and the mastering of technical skills. However, critical incident reporting and observational studies, both in the clinical setting and on patient simulators, have identified non-technical skills to be major determinants of successful anesthesia crisis management. Non-technical skills are those that do not relate to medical knowledge or technical procedures but instead encompass cognitive skills (e.g., decision making, situation awareness) and interpersonal skills (e.g., exchanging information, assertiveness). These qualities are not necessarily acquired by anesthesia trainees through routine clinical experiences and may need to be specifically taught."

Given the importance of situation awareness in the provision of safe anesthesia care, the proposed study is justified because it will examine the contribution that individual attributes (memory, cognition, and automaticity) make to the acquisition of situation awareness. This work will test Endsley's theory of situation awareness in the GSRNA population.

Conclusion

The following paper is divided into four remaining chapters. Chapter Two provides a comprehensive literature review which analyzes the current body of knowledge related to situation awareness in complex systems, including anesthesiology. Endsley's theory of situation awareness is also presented and discussed. Chapter Three describes the proposed scientific methods and statistical analyses that will be used to answer the research question. Chapter Four will offer an objective and succinct presentation of the study results. Finally, Chapter Five will provide a summary and interpretation of the study results.

CHAPTER 2: LITERATURE REVIEW

According to The Joint Commission (2007), United States (US) hospitals continue to demonstrate steady improvements in health care quality and patient safety. These improvements have resulted in saved lives, better health, enhanced quality of life, and lower health care costs. Although this progress is encouraging, much room for improvement remains (The Joint Commission, 2007). The Joint Commission Sentinel Event database lists peri-operative complications among documented adverse events which lead to serious patient injury and death. Peri-operative human factors with a disposition to error are showcased in the database and include, for example, inadequate communication, incorrect assessment of a patient's physical condition, and inadequate orientation and training of health care professionals.

Health care in the US is the output of a large and complex system comprised of many interacting, interrelated, and interdependent parts. One discipline within the US health care system which is practiced within a similarly complex subsystem is anesthesiology. Just as our health care system is a complex arrangement in which health care is delivered, the practice of anesthesia is a complex arrangement in which anesthesia is delivered (Pott, Johnson, & Cnossen, 2005). An understanding of complex systems is necessary to realize the potential for human error in such dynamic environments.

Comprehension of the mechanisms of human error is important when the consequences of a failed complex system are potentially devastating.

In this chapter, the most current understanding of complex systems is provided as a foundation to examine the dynamic nature of anesthesia practice. A discussion of the opportunity for human error in anesthesia is offered to illuminate the consequences of error and to provide an understanding of how systems can potentially fail. An analysis of relevant literature establishing the essential linkage between the importance of situation awareness on the part of health care workers, including those in anesthesia, to complex systems is presented. An assessment of cognitive psychology literature reveals the relevance of situation awareness to anesthesia practice and how the lack of situation awareness may contribute to human error (Figure 1). Finally, the theory of situation awareness is described and scrutinized and studies which have employed the theory of situation awareness are evaluated.

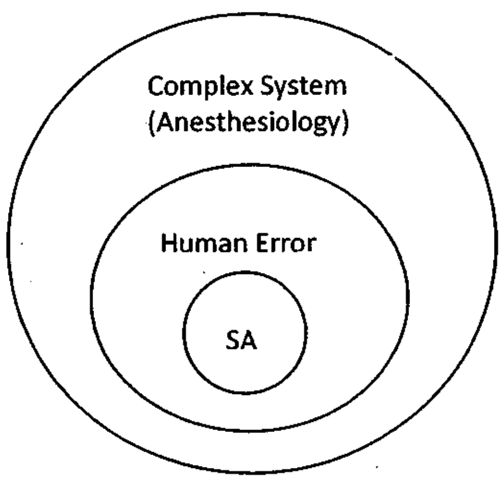

Figure 1: Schematic representation of the link between SA and anesthesiology.

Complex Systems

Complex systems are sometimes referred to as 'high-risk' systems. Industries such as aviation, nuclear science, military operations, and medicine have all been identified as high-risk operating systems (Gaba, 1994). Perrow (1999) characterizes complex systems as those with multiple levels of dynamic components which are non-linear, highly interactive, and tightly-coupled. Non-linearity describes the output or outcome of a system as more than the sum of each individual part and refers to the notion that components of a system may serve many purposes. Problems arising in a non-linear operating environment are difficult to solve and give rise to potential chaos (Khalil, 2001).

Petros (2003) discusses the profound influence non-linearity has on the practice of medicine. He argues that disciplines of medicine are not linear subjects and, in this context, "one and one do not always make two" (pg. 172). In one example, Petros (2003) describes how just a small medical intervention may spark a chain of events in the non-linear environment of the human body which may "profoundly disturb" its balance (p. 172). He posits that things in nature are complex and non-linear and have a propensity to self-organize to achieve homeostasis. Biological systems, therefore, are particularly vulnerable to chaos and disaster when the non-linearity of their control mechanisms are ignored during medical intervention and treatment (Petros, 2003).

In a between-subjects quasi-experimental design, Olsson, Enkvist, & Juslin (2006) studied analytical (rule-based) thinking vs. intuition (exemplar memory) in the performance of linear vs. non-linear tasks in 66 undergraduate students. The authors hypothesized that people are unable to use analytical processes in non-linear judgment tasks; to be successful they must shift to the use of exemplar memory or intuition. Although researchers were unable to support their hypothesis, they found a significant difference in performance between linear and non-linear tasks, with non-linear tasks being the most difficult to learn and most associated with poor performance.

High-level interactions inherent in complex systems are described as abstract, unfamiliar, unplanned, unexpected, invisible, and/or incomprehensible (Perrow, 1999). The nature of high-level interactions lends itself to the formation of unknown feedback mechanisms and a lack of redundancy often recognized as requisite characteristics of optimally functioning systems (Perrow, 1999). Orderly functioning of complex systems is dependent, in part, upon the operator's understanding of the dynamics of all components with which he or she interacts and the significance of all types of information produced by and within the system (Cannon-Bowers & Salas, 2006).

Coupling is defined as the association between an action and its consequences. Complex systems are characterized as having tightly-coupled parts, units, and sub-systems. The term tightly-coupled refers to a quality that prevents timely recovery from adverse events and leaves little to no room for error (Perrow, 1999). The degree of coupling in a system dictates complexity. Tightly-coupled systems demonstrate strict and invariant sequences, contain very little slack, and are not stagnant as they demand attention (Perrow, 1999). In computer science, for example, tight coupling describes a system in which hardware and software are not only linked together, but are also dependent upon each other.

Strauch (2004) describes complex systems as those that perform numerous tasks simultaneously and involve some human element. Complex system operators, acting as just one component of a system, often serve as monitors and high-level managers of an ever-increasing presence of automation. According to Strauch (2004), the human element is necessary to control the environment and obtain and interpret essential information to ensure the system's success. As technology and complexity of systems move forward, Strauch (2004) emphasizes the need for operators to perform at a higher cognitive and lower physical level.

The field of aviation has been identified as the epitome of a complex operating system, one of whose primary objective is passenger safety (Stanton, Chambers & Piggott, 2001; International Civil Aviation Organization, 2004; Ripley & Larkin, 2005). In congruence with Perrow's (1999) description of complex systems, nonlinearities are a feature of aircraft dynamics and flight control systems which require rapid response to achieve stability and performance (Sivasundarum, 2000). The pilot-automation interface describes a high-level interaction which is central to the development of advanced air traffic management (Callantine & Crane, 1999). Many facets of aviation are tightly-coupled whereas adverse incidents can quickly spiral out of control. Untoward consequences can rapidly ensue before operators are able to understand the situation and perform necessary corrective actions. In aviation, as well as in many other complex systems, trivial incidents can snowball in unpredictable ways and with possibly severe consequences.

Anesthesiology as a Complex System

Similar to aviation, anesthesia practice is a complex domain characterized by uncertainty, contingency, dynamism, high information load, risk, and non-linear sequences of activities at many levels (Gaba & Howard, 1995; Pott, Johnson & Cnossen, 2005; Runciman, Merry & Wolton, 2005). Anesthesia providers must effectively, efficiently, and simultaneously control and manage multiple, non-linear, high-level, and tightly-coupled components. These include rapidly-acting and potentially lethal medications, indirect measurements of critical vital signs, a chaotic operating room environment, highly technical equipment, invasive procedures, and the abstract nature of anesthesia and its effects on human anatomy and physiology.

In a 2006 study, Kumaraswami et al. queried anesthesia providers about the complexity of intra-operative events. The researchers found that patient positioning, endotracheal tube placement and verification, patient acuity, regional anesthesia, and central and peripheral intravenous line placement are among the most common factors contributing to the complexity of anesthesia. Anesthesia is determined to be a high-risk and complex practice in that every intervention is burdened with a plausible opportunity for patient injury (Gaba & Howard, 1994; Pott, Johnson, & Cnossen, 2005; Wright, 2006). In the anesthesia arena, effective performance requires expert knowledge, appropriate problem-solving skills, vigilance, and rapid responses to deteriorating conditions (Weinger & Slagle, 2002).

As technology becomes a more integral part of a system and the number of interdependencies grows between applications, complexity within the system further develops. The advent of state-of-the-art technology such as the Bispectral Index (BIS) monitor, computerized charting, and capnography, adds to the complexity of anesthesia practice. Barker (2003) believes the presence of advanced technology in operating rooms requires essential cognitive skills in the integration of copious amounts of data, in addition to requisite knowledge of pharmacology, physiology, and other operating room systems. For example, Weinger, Herndon, and Gaba (1997) found that the use of transesophageal echocardiography by anesthesia providers during coronary artery bypass graft surgery may adversely affect clinical vigilance and workload distribution. Because the difference between a trivial event and an adverse event in anesthesia often rests on the anesthesia provider's shoulders, the addition of technology to the operating room landscape adds further burden and potentially, an additional layer of complexity.

The management of a myriad of monitoring equipment and anesthesia machines is becoming increasingly complex. Doyle (2001) found many subtle complexities related to the operation of a specific brand of a newly-introduced anesthesia machine. Special challenges related to this particular machine include software design flaws that rendered the machine error-prone if the machine is checked with a popular anesthetic vaporizer in place. Other problematic features of this particular anesthesia machine include an oxygen flow default that is set to the "off" position upon completion of the machine check, a delay in ventilator function once the ventilator is switched to the "on" position, virtual (digital) versus real (mechanical) gas flowmeters, and unreliable capnography data. It is not unusual to see up to five or more different types of anesthesia machines, each with their own idiosyncrasies, throughout the operating rooms of one hospital system for which anesthesia providers are responsible. It is recommended that anesthesia providers have a thorough understanding of the operations of each type of anesthesia machine they may potentially use (Manley & Cuddeford, 1996; Eisenkraft, 2005; American Association of Nurse Anesthetists, 2007).

Just as Perrow (1999) describes high-risk environments as those that are complex and tightly coupled, Gaba, Fish and Howard (1994) describe anesthesia as complex and tightly-coupled. At the individual level, patients are very complex with tightly-coupled anatomical and physiological systems. For example, rarely will pathology cripple the respiratory system without an adverse influence on the cardiovascular system. Proper functioning of the cardiovascular system will not sustain itself without quick attention to the respiratory insult. Additionally, many physiological functions of the human body are non-linear: independently, the lungs and the heart are incapable of sustaining life. On a systems level, operating room teams are similarly complex and tightly-coupled. For example, should a surgeon inadvertently rupture a main artery during the course of surgery, major loss of blood would result. A delayed response on the part of the anesthetist to adjust for the blood loss in this instance can contribute to adverse consequences in the form of poor patient outcomes (Gaba, Fish & Howard, 1994). In the operating room environment, actions or inactions of just one team member can swiftly and very powerfully influence other parts of the system.

All of the aforementioned factors associated with anesthesia practice conflate to cause information overload which, in turn, adds to its complex nature. The anesthesia provider is responsible for perceiving and comprehending an inordinate amount of sensory input in a fast-paced environment, rich with distractions. Endsley & Garland (2000) proclaim that more data, a by-product of more technology and monitoring systems, does not necessarily mean more meaningful information. These researchers agree that complex systems produce so much data, that it is often difficult to find "what is needed, when it is needed", leaving operators inadequately informed and cognitively and physically handicapped as they attempt to manage the complexity of their environment (p. 4).

Anesthesia services are provided within a dynamic socio-technical system that has the capability of reaching a number of different states of complexity (Pott, Johnson, & Cnossen, 2005). Similar to other complex operating environments, the practice and delivery of anesthesia is characterized has having non-linear, highly-interactive, and tightly-coupled components. Anesthesia providers, as operators in this complex domain, are not immune to human error and must have a thorough understanding of salient elements in their environment as well as possess the requisite skills to function effectively.

Human Error in Complex Systems

Any complex system harbors a proneness to error given the interaction among people, materials, machines, facilities, and procedures (Chapanis, 1996; Perrow, 1999). The study of human error in complex systems such as aviation, nuclear power, military operations, and medicine remains fertile ground for improving quality and enhancing the safety of all stakeholders.

The cognitive study of human error is a vast field borne as a development of human factors engineering which is concerned with improving performance and enhancing safety in the human-environment relationship (Reason, 1990). Although numerous theories and frameworks are associated with the study of human error, two well-recognized and prominent human error researchers, Reason (1990) and Rasmussen (2003), have developed theories particularly appropriate for the study of human error in the anesthesia environment.

Reason's Swiss Cheese Model

The Swiss Cheese Model of human error describes the opportunity for error as a product of active failures and latent factors embedded in a system's defense mechanisms (Reason, 2000). In this model, the slices of Swiss cheese symbolize system defense mechanisms where active failures and latent factors are represented as holes in the slices of cheese. When the holes in each slice of Swiss cheese come into proper alignment, a course for error is created (Figure 2). According to Reason (2000), an active failure is defined as any unsafe act perpetrated by persons in contact with the system. These are more commonly referred to as slips, lapses, and mistakes. Latent factors are described as dormant mechanisms living within a system that create an accident opportunity only when they come in contact with active failures. Latent factors include those caused by realities such as production pressure, scheduling difficulties, insufficient equipment, fatigue, and improper training.

Reason's (1990) model of human error has become the dominant paradigm for analyzing errors in complex systems (Perneger, 2005). The Swiss Cheese Model does

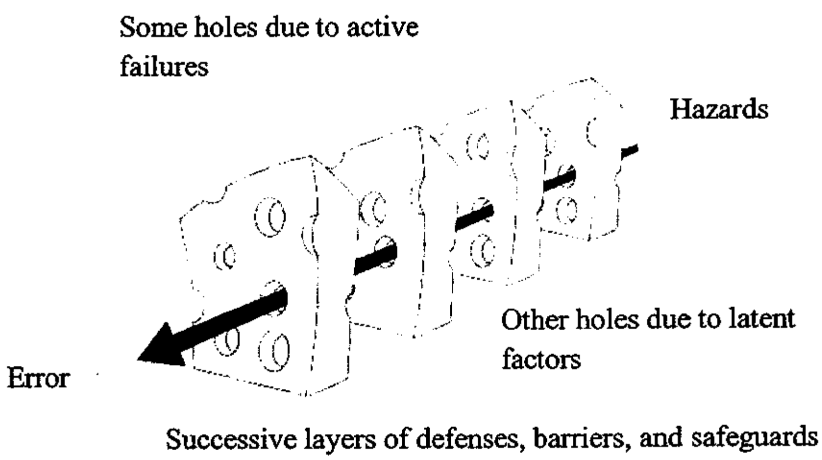

Figure 2: The Swiss Cheese Model of human error .

Source: Reason, J. (1990). Human error: Models and management. British Medical Journal, 320, p. 770.

not incorporate mechanical or technical contributions to error; its primary focus is on the human components of system failures since decades of accident analyses expose human error as the dominant risk in complex environments (Reason, 1990; Perrow, 1999; Strauch, 2005). Reason (1990) identifiesacts, and inappropriate responses to situational demands as contributing factors to the commission of error.

From their work with the Office of Aviation Medicine, Shappell and Weigmann (2000) found that human error was implicated in 70 to 80% of all civil and military aviation accidents. Based on this finding, they employed the Swiss Cheese Model as the ideal framework to study hundreds of military aviation accident reports and developed the Human Factors Analysis and Classification System (HFACS). The goal of HFACS is to reduce the frequency of aviation accidents through the use of systematic error reporting methods and objective evaluation of intervention programs.

After reviewing data from the Institute of Medicine (1999) and the National Safety Council (2004), Dekker (2007, p. 177) revealed that "up to 1 in 7 doctors will kill a patient each year by mistake" where "up to 1 in 53,000 gun owners will kill somebody by mistake" determining that doctors are 7,500 more times as likely than gun owners to kill a person as a result of human error. Dekker's self-described facetious comparison is to showcase that such error counting has long been the mainstream method used for evaluating safety in organizations and professional groups. Dekker (2007) explored the Swiss Cheese Model, as well as other human error methods, as an approach to understanding safety in complex systems to support the development of alternative and more reasonable error counting methods.

Likewise, Wilson et al. (2007) employed Reason's model as a foundation to construct a taxonomy of cognitive breakdowns which contribute to fratricide in the military population. Similarly, the medical literature reveals applications of the Swiss Cheese Model to explore issues of improved quality, expanded access, and patient safety (Agency for Healthcare Research and Quality, 2007; Kalisch & Aebersold, 2006; Chassin, 2008).

Rasmussen's Model

A related theory, Rasmussen's model, explores cognitive aspects of error from a behavioral standpoint. Rasmussen (2003) suggests that error stems from cognitive behavior in three hierarchical categories: skill-based, rule-based, and knowledge-based.

Elements comprising each category are contingent on and adaptable to the requirements of the specific discipline and industrial sector. Skill-based behavior takes place without conscious control where task execution is highly automated. Rule-based behavior includes the execution of tasks guided by stored rules, policies, and/or procedures (Wentink et al., 2003). Knowledge-based behavior is used largely in complex and unfamiliar environments where chunks of conceptual information serve as the basis for reasoning and planning. Progression through the various levels is accomplished by recoding and interpreting environmental stimuli (Kass, Herschler, & Companion, 1991). Recoding stimuli into relevant and irrelevant units serves to simplify the environment.

Rasmussen (2003) posits that human beings are fallible and an approach to understanding human error, particularly in unstable, ill-structured, and dynamic environments, must consider behavior and cognitive functions such as attention, comprehension, anticipation, and symbolic reasoning rather than a focus solely on error attribution. The human worker, Rasmussen suggests, is a well-positioned agent of change; one that can continuously adapt and learn in order to reduce the incidence of error and improve the outcomes of a system (Sheridan, 2003).

Rasmussen's (2003) model explains that under stable conditions, experience develops in a routine manner and normal ways of doing things emerge. In complex environments, however, operator performance must include continuous awareness of the situation and strategies for making critical decisions under stress. The processes by which effective strategies are chosen vary from one operator to the next, given the boundaries defined by work requirements and available resources. Individual variations in decision-making and work strategies, and hence work performance, are attributed to physical and mental processes such as the level at which the individual perceives and interprets information. As an individual adapts to his or her work environment, exploring the consequences of tentative decisions and acceptable variations of work strategies, errors will be unavoidable side effects (Rasmussen, 2003).

Wentink et al. (2003) applied Rasmussen's framework to examine training objectives, needs, and methods for laparoscopic surgery. The researchers assessed the level of skill-, rule-, and knowledge-based behavior necessary for laparoscopic surgery in an attempt to determine objectives of training. They explored which particular skill-, rule-, and knowledge-based behaviors should be trained and then asked how training could incorporate the promotion of all three levels of human behavior to determine the appropriate methods of training. The investigators recommend the use of virtual reality trainers which have the potential to develop all levels of human behavior to promote maximum safety and avoid error during the complex procedure of laparoscopy.

Kass, Herschler, and Companion (1991) employed Rasmussen's model of human behavior to examine whether different training strategies enhanced acquisition of pattern recognition skills in 20 civilian volunteers in a simulated tank battlefield environment. The researchers believed that recognition of patterns is a skill-based behavior that may enhance one's awareness of his or her environment leading to superior performance. The study findings demonstrated that the acquisition of pattern recognition skills under complex conditions is less likely than their acquisition in a less stimulating environment.

Human Error in Anesthesia

Human error has been shown to be a main cause of accidents in medicine and continues to be a topic of considerable importance (Nyssen & Blavier, 2006). The Institute of Medicine (2001), in its publication "To Err is Human: Building a Better Health System", provides several explanations for common errors in medicine. They include, but are not limited to, error in diagnosis, error in the performance of an operation, error in administering a treatment, inadequate monitoring, failure of communication, and errors in drug administration. All of these instances involve some human component.

A synthesis of case studies discovered in the medical literature reveals the impact of human error in anesthesiology. Many studies over the last two decades associate human error in anesthesia with lack of attention, inadequate preparation, environmental limitations, clinical misjudgments, insufficient awareness, flawed decision making, as well as physical and emotional factors.

Caplan, Ward, Posner, & Cheney (1988) investigated 14 cases of sudden cardiac arrest in otherwise healthy patients undergoing a spinal anesthetic. They hypothesized that an in depth analysis of the anesthetic management of these anesthesia mishaps would reveal common themes in the provision of care which left one patient dead and seven others with debilitating neurological damage. The investigators found two clinical situations to be present during the cardiac arrest incidents. First, was the use of sedative medications to the point that the affected patients were not verbal during the placement of the spinal anesthetic. The frequency of cases (n=6) demonstrating a lack of patient verbalization lead the researchers to consider that respiratory insufficiency may have gone unrecognized, despite the administration of appropriate doses of sedatives. The second clinical practice pattern identified as common among cardiac arrest incidents in this analysis was inadequate comprehension of the interaction between sympathetic blockade during spinal anesthesia and cardiopulmonary resuscitation. The researchers hypothesize that a better understanding of this relationship may have lead to more prompt, appropriate, and effective treatment.

Bhananker et al. (2006) reviewed closed malpractice claims (n=121) from the American Society of Anesthesiologists (ASA) Closed Claims database from 1990 to 2006 to compare the incidence of patient injury and liability during monitored anesthesia care (MAC), also known as sedation, versus the incidence of patient injury and liability during general and regional anesthesia. The researchers found the incidence of death or brain damage was similar in MAC and general anesthesia cases, both exceeding the incidence associated with regional anesthesia. The researchers also discovered that an overdose, either relative or absolute, of sedative medications was most often associated with patient death and brain damage in the MAC group; almost half of these accidents were identified as preventable with better monitoring, audible alarms, and improved provider awareness.

Domino, Posner, Caplan, & Cheney (1999) analyzed data of the ASA Closed Claims Project to illuminate the incidence and contributing factors associated with awake paralysis and patient awareness under general anesthesia. Awake paralysis describes a condition where the patient is not yet anesthetized, but pharmacologically paralyzed.

Patient awareness is defined as the patient's ability to recall intraoperative events which occurred during general anesthesia. Domino et al. (1999) discovered 18 cases of awake paralysis and 61 cases of awareness under general anesthesia in the database. The investigators used logistic regression to identify patient and anesthetic factors associated with these adverse anesthesia events and found that while patient factors such as gender (female > male) and choice of anesthetic were most associated with awareness under general anesthesia, mislabeled medication syringes and inadequate vigilance were most associated with awake paralysis.

Due to easy access to highly potent and potentially harmful medications used in anesthesia, drug administration errors continue to be an area of research interest in this discipline. Bowdle (2003) examined the ASA Closed Claims database for cases involving drug administration errors. He discovered that during the 1980's and 1990's, 4 percent of the total database cases involved drug errors. The majority of drug errors involved either substituting a wrong drug for a correct drug, inadvertently administering a drug that was never intended to be given, and administering an overdose of an intended drug. Patient injury caused by drug administration errors ranged from no injury, minor injury, major injury, and death.

Auweiler et al. (2005) report three cases of a guidewire (a small, thin, flexible wire used over which to thread a central intravenous catheter) found left inside of patients who had undergone central intravenous catheter placement. The first case involved an 85 year-old patient undergoing a rectal resection for adenocarcinoma. After general anesthesia was induced for the surgical procedure, a central intravenous line catheter was placed in the patient's right internal jugular vein for intravascular fluid management. Post-operatively, the patient complained of right neck pain, which resolved spontaneously and the patient was discharged home. Three months later on a follow-up appointment, a chest radiograph revealed the guidewire lodged in the superior vena cava and right cardiac ventricle. The second patient had a central intravenous catheter placed upon admittance to the hospital for sepsis. Upon successful treatment of her condition, the patient was discharged home only to return a month later for gastrointestinal bleeding. On this admission, a chest radiograph was taken and the guidewire was found in the patient's vasculature. The third case involved a 50 year-old male undergoing coronary artery bypass grafting under general anesthesia. Once anesthetized, a central intravenous line was placed and the surgery ensued. On post-operative Day 4, the patient developed lower limb thrombosis and a chest radiograph revealed the central line guidewire in the patient's right superior vena cava, through his right heart, down the inferior vena cava and into his pelvic vasculature. In conclusion, the investigators identified a retained guidewire as a serious but preventable error, leading to potentially devastating consequences. The researchers suggest heightened awareness and focused attention on the part of the practitioner as suggestions for improved patient outcomes related to central line placement.

Using a modified critical-incident analysis, Cooper, Newbower, Long, and McPeek (2002) retrospectively studied 359 preventable anesthesia-related incidents in anesthesia at one large metropolitan teaching hospital. They identified a critical incident as an occurrence that had the potential to or did lead to an untoward patient outcome.

The researchers found that 82% of preventable incidents, including breathing circuit disconnections, inadvertent changes in gas flow, and drug syringe errors, involved human error. The researchers also discovered other human factors, including inadequate communication, lack of precaution, and environmental distractions as contributors to critical incidents.

Through a review of anesthesia literature, Aitkenhead (2005) analyzed the epidemiology of injuries and death associated with anesthesia since the 1980's. His meta-analysis reveals factors involved in anesthesia-related deaths to include failure to apply knowledge, lack of care, lack of experience, failure of equipment, and fatigue. Aitkenhead (2005) detailed a study by Kawashima et al. (2003) which investigated cardiac arrest during anesthesia in Japan between 1994 and 1998. Kawashima et al. (2003) described common causes of intra-operative cardiac arrest to include drug overdose and drug selection error, myocardial infarction, inadequate airway management, high spinal, and inadequate vigilance. Aitkenhead (2005) also included the work of Arbous et al. (2001) who found that anesthesia mortality in the Netherlands was largely due to poor pre-operative assessment, inappropriate anesthetic technique, poor management of ventilation, and inadequate monitoring. Aitkenhead (2005) concludes that, despite advances in technology and standards of practice, patient safety will continue to be highly dependent on education, training, attitudes, and persistent audit and vigilance.

The Australian Incident Monitoring Study

One of the largest research endeavors to examine critical incidents in anesthesia is the Australian Incident Monitoring Study (AIMS) (Aitkenhead, 2005). AIMS is an initiative designed to systematically capture information from a wide variety of sources in an attempt to classify anesthesia-related sentinel events. Since 1993, AIMS has recorded such anesthesia mishaps as undetected breathing system disconnections, drug overdose, erroneous drug administration, and problems with intubation, extubation, and controlling the patient's airway. AIMS lists common human factors associated with these critical incidents as inexperience, haste, failure to check equipment, unfamiliarity with equipment, poor communication, restricted visual field, distraction, fatigue, decreased vigilance, and inattention (Aitkenhead, 2005).

The ASA Closed Claims Project

Most anesthesia-related accidents are preventable and involve human error (Cooper, Newbower, Long & McPeek, 2002; Weinger & Slagle, 2002; Aitkenhead, 2005). Anesthesia-related accidents, while rare, are worthy of continuous analysis and research because of their catastrophic potential. It is important to include the ASA Closed Claims Project in this discussion on human error in anesthesia practice because it is a highly-regarded and evidence-based ongoing investigation of over 7,000 closed anesthesia malpractice claims. Since its inception in the mid 1980's, the Project has identified several contributors to loss and injury and has provided the anesthesia profession with effective strategies for quality and safety improvement. Claims reported to the Project database have revealed common human errors to include lack of attention, haste, fatigue, stress, information overload, failure to communicate, unrecognized breathing circuit disconnection, mistaken drug administration, airway mismanagement, anesthesia machine misuse, and intravenous line disconnection, to name a few (ASA Closed Claims Project, 2008).

The AANA Foundation Closed Malpractice Claims Database

The AANA Foundation Closed Malpractice Claims Database is as equally important to this discussion as the ASA Closed Claims Project as it contains over 300 reported cases involving Certified Registered Nurse Anesthetists (CRNAs) from throughout the US. Information is provided to this database from claims submitted to the St. Paul Fire and Marine Insurance Company, a major malpractice insurer of CRNAs (Jordan, Kremer, Crawforth & Shott, 2001). Through a retrospective, triangulated, descriptive research design, Kremer, Faut-Callahan & Hicks (2002) examined 84 cases involving cognitive errors made by CRNAs that were implicated in adverse anesthesia outcomes. Statistical analysis of the data collected from these 84 cases revealed suboptimal clinical decision-making in the areas of pre-induction activities, use of technical monitoring, methods of anesthesia care, and preventability of a damaging event.

Cook and Woods (2001) suggest that a focus on the thought processes and behaviors of individuals, rather than on the attribution of error, may be one of the most productive methods for reducing the catastrophic potential intrinsic to complex systems. Similarly, the work of Rasmussen (2003) and Reason (1990) proposes that in order to understand human error in complex systems, further empirical attention should be directed toward the cognitive aspects of human behavior rather than on errors themselves.

One such construct of cognition which commands attention in the study of complex systems is situation awareness (SA) (Gaba & Howard, 1995; Endsley & Garland, 2000; Stanton, Chambers, & Piggott, 2001; Pott, Johnson, & Cnossen, 2005; McIlvaine, 2007).

Situation Awareness and Human Error

Situation awareness is a three-level construct and is defined at the individual level as one's perception of the elements in the environment within a volume of time and space (Level 1), the comprehension of their meaning (Level 2), and the projection of their status in the near future (Level 3) (Endsley, 1988). Situation awareness is an integral and requisite component for optimal performance and effective decision making in dynamic and complex environments (Endsley et al., 1999, 2001; Stanton, Chambers & Piggott, 2001). In defining SA, it is helpful to differentiate between errors related to SA and errors related to decision-making. An error in decision-making is one in which the operator makes an incorrect decision, based on a correct mental picture. An error in SA is one in which the operator may make a correct decision, but one that is based on an incorrect or incomplete mental picture (Endsley, 1999).

In the Swiss Cheese Model of human error, inadequate SA is a latent factor, described by Reason (1990) as a dormant mechanism living within a system that has the potential to create an accident opportunity should it come in contact with active failures. Many errors in health care are the result of latent factors of a system where health care providers are part of, but not instigators of, those errors (Lowe, 2006). With an understanding of the cognitive mechanisms that support SA, recommendations can be made for designing systems and training programs that enhance operator SA (Endsley, 1999). According to Reason (1990), identifying and minimizing latent factors can have a profound impact on the safety of a system.

Rasmussen's (2003) framework, suggesting error as a product of adaptation to the work environment which is guided by skill-, rule-, and knowledge-based behaviors, can be used to understand situation awareness (Table 1). In their study of situation awareness in a simulated battlefield environment, Kass, Herschler & Companion (1991) categorized situation awareness as a skill-based behavior, resulting from the processes by which environment information is extracted, integrated, assessed, and acted upon. An understanding of the underlying mechanisms by which individuals acquire situation awareness may, in theory, improve human behavior in complex situations in a way that improves safety and reduces error.

In complex systems, lack of SA is associated with accidents, error, and poor system performance (Nagel, 1988; Stanton, Chambers, & Piggott, 2001; Stripe et al., 2006). Hartel, Smith & Prince (1991), in their study of over 200 military aviation accidents, found the leading causal factors to include problems related to SA. Similarly, Endsley (1995) found that over 80% of human-error related adverse events among major airlines could be attributed to inadequate SA; more than improper decision-making or inadequate flight skills. Studies investigating air traffic control accidents reveal that over half of the operation errors were related to inadequate or misdirected SA (Rodgers & Nye, 1993; Endsley & Rodgers, 1998; Durso et al., 1998; Rodgers, Mogford & Strauch, 1999).

Table 1

Rasmussen's Taxonomy Adapted to Human Errors in Anesthesia

Cognitive Mechanism	Human Factor - Anesthesia
Skill-Based	Inattention Distraction Inadequate situation awareness Lack of patient care Drug administration error Unsuccessful airway management Unsuccessful regional anesthetic Unsuccessful invasive line placement
Rule-Based	Failure to check anesthesia machine Failure to individualize care plan Use of inadvisable anesthetic technique Pre-mature extubation of trachea Violation of sterile technique Inadequate verification of endotracheal tube
Knowledge-Based	Errors of judgment Wrong medication chosen Wrong anesthetic chosen Misdiagnosis of patient problem Inexperience Insufficient preparation for anesthetic

Adapted from Marcus (2005) p. 244.

Intuition suggests there may be individual differences in the ability of operators of complex systems to develop SA. Despite a plethora of anecdotal evidence supporting this speculation, only one such study was discovered as a result of a review of aviation, psychology, human factors, patient safety, health care quality, and medical literature.

Bolstad and Endsley (1994) conducted an investigation to determine whether SA abilities vary between individual pilots and to identify specific characteristics that may contribute to the development of SA. With an acknowledgement of approaches to improving SA by improving system design processes, Bolstad and Endsley (1994) also considered enhancing SA at the level of the individual through education and training. By studying 21 experienced male fighter pilots' innate potential for SA, the researchers hoped to promote SA in already existing aviation designs.

Bolstad and Endsley's (1994) study, based largely on Endsley's theory of situation awareness, tested the relationships between spatial ability, attention, memory, perception, cognitive function, and locus of control and SA. The independent variables were measured by a battery of valid and reliable psychometric exams. The dependent variable, SA, was assessed by the Situation Awareness Global Assessment Technique (SAGAT), a discipline-oriented and subjective measurement of SA in simulations of specific task environments. Bolstad and Endsley (1994) found that individual differences in SA do exist. The investigators hypothesized that individual differences in SA would be constant within subjects; this hypothesis was supported with test-retest reliability scores ranging from .92 - .98. Scores for each subject on 31 variables (variables include subsets of each independent measure) were correlated with SA scores using a Pearson pairwise correlation matrix. They discovered a moderate correlation between measures of spatial (r=.317, r=.354, r=-.354) and perceptual (r=-.448, r=.366, r=-.547) skills and SA and partial support for a relationship between attention (r=-.250) and pattern-matching (r=.243) and SA. No support was found for a relationship between memory and analytical skills and SA. The researchers encourage further empirical study focused on different measures of these same attributes and their correlation with SA as well as additional studies of SA in operators of other complex environments to gain a better understanding of individual factors related to SA.

Situation Awareness in Anesthesiology

The study of situation awareness is important in any environment where humans are required to perform complex tasks under highly dynamic conditions involving multiple and highly-interactive stimuli which must be continuously identified, interpreted, and processed (Blanchard, 2007). Despite well-described and commonly-accepted links between SA and complex systems (Barker, 2003; Pott, Johnson & Cnossen, 2005; Kumaraswami et al., 2006) and complex systems and anesthesiology (Gaba, Fish, &Howard, 1994; Weinger, Herndon, & Gaba, 1997), there is a paucity of current research that specifically and empirically examines individual differences in SA in anesthesiology.

Human factors have been identified as the cause of many preventable accidents in anesthesia and SA is hypothesized to be one such human factor (Gaba & Howard, 1995; Endsley, 1995). It is essential, given the multitude and complexity of tasks for which they are responsible, that anesthesia providers possess the ability to perceive all elements of the patient's condition and operating room environment, comprehend their meaning, and project the status of them into the near future. Just as SA is critical in maintaining safe control of an aircraft (Stanton, Chambers & Piggott, 2001), it is essential that anesthetists acquire and maintain SA to avoid adverse outcomes and to enhance quality of care and patient safety.

Barker (2003) suggests that SA in anesthesia practice is crucial for making appropriate decisions, forecasting adverse events, preventing error, following proper procedure, and communicating with operating room personnel. As advances in technology and an aging patient population continue to add to the already extraordinary level of complexity in the operating room environment, adequate levels of SA are necessary. Anesthesia providers must be adept at perceiving dynamic situations accurately, comprehending their consequences and significance, and anticipating all possible changes to the current condition.

Through a review of the anesthesia literature from 1990 – 1994, Gaba and Howard (1995) reason that key aspects of situations in anesthesia require an anesthesia provider's awareness. Rapidly changing and sometimes subtle cues originating from many different sources place excessive burden on an anesthetist's attention and cognitive abilities. Evolving situations resulting from actions, inactions, the passage of time, or the presence of new information need to be detected and interpreted in a timely and accurate manner. Aberrant characteristics of patients, procedures, team members, and the operating room environment challenge the anesthesia provider and require recognition and shrewd management over-and-above those necessary for ordinary situations.

Theoretical Underpinnings of Situation Awareness

The concept of SA has a solid foundation in aviation and can be traced as far back as World War I. To stay alive and successfully complete their mission, fighter pilots needed to keenly observe their opponent's every move and anticipate their next move a fraction of a second before they could observe and anticipate their own (Gilson, 1995). This idea has implications for quality improvement and safety enhancement in many complex system domains.

Several researchers have contributed to the body of knowledge related to SA by composing theories to explain this construct (Fracker, 1988; Spick, 1988; Endsley, 1988, 1995; Taylor, 1990; Adams et al., 1995; Klein, 1995; Smith & Hancock, 1995). The most prominent theories of SA are based on some model of information processing theory which details the cognitive processes and memory components important for the development of SA (Fracker, 1988; Taylor, 1990; Adams et al., 1995; Endsley & Garland, 1988, 1995; Smith & Hancock, 1995).

The dominant view of information processing theory proposes that information is processed and stored in three stages with a heavy emphasis on memory (Atkinson & Shiffrin, 1968). According to information processing theory, environmental energy is transduced into meaningful information and creates sensory memory which lasts between one-half of a second and three seconds. Attention is a key factor in determining what moves from sensory memory to short-term memory. Short term memory, also referred to as working memory, is created by allocating attention to external stimuli or internal thoughts. Short term memories have been shown to last between 15 and 20 seconds, unless repeatedly rehearsed, then may last up to 20 minutes. Short-term memories move into permanent long-term storage with repeated rehearsal and meaningful association (Kandel, 2001). Long-term memories are organized into schemas and are important in the efficient use of related chunks of stored information. Long-term memory has a powerful influence on attention allocation and perception; that is, prior knowledge affects how information is perceived and processed (Winn & Logie, 1998; Ashcraft, 1994).

Endsley's (1988) is an established and well-accepted theory of SA which emerged from information processing theory as a need to understand how operators of complex systems select, process, and interpret information on a continual basis. Before SA was studied by Endsley in the 1980's, it was speculated that operators gained this ability through extra-sensory perception (ESP) or by instinct (Spick, 1988). Endsley (1988) suggests that perhaps there are personal attributes, including preconceptions, memory, attention, automaticity, cognition, and experience involved in the ability to acquire and maintain SA (Figure 3).

Endsley's Theory of Situation Awareness

Although there have been many attempts to clearly define SA, a general and well-accepted definition describes SA as "one's perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future" (Endsley, 1988, p. 9; Bedny & Meister, 1999; Smith & Hancock, 1995). Time refers to how soon an element will influence the operator's goals, while space refers to how far away an element is. In highly dynamic environments, temporal aspects of SA become very important for acquisition of Levels 2 and 3 (described below) because at these levels, operators must constantly adapt cognitive processes and skills in order to maintain SA (Endsley, 2000).

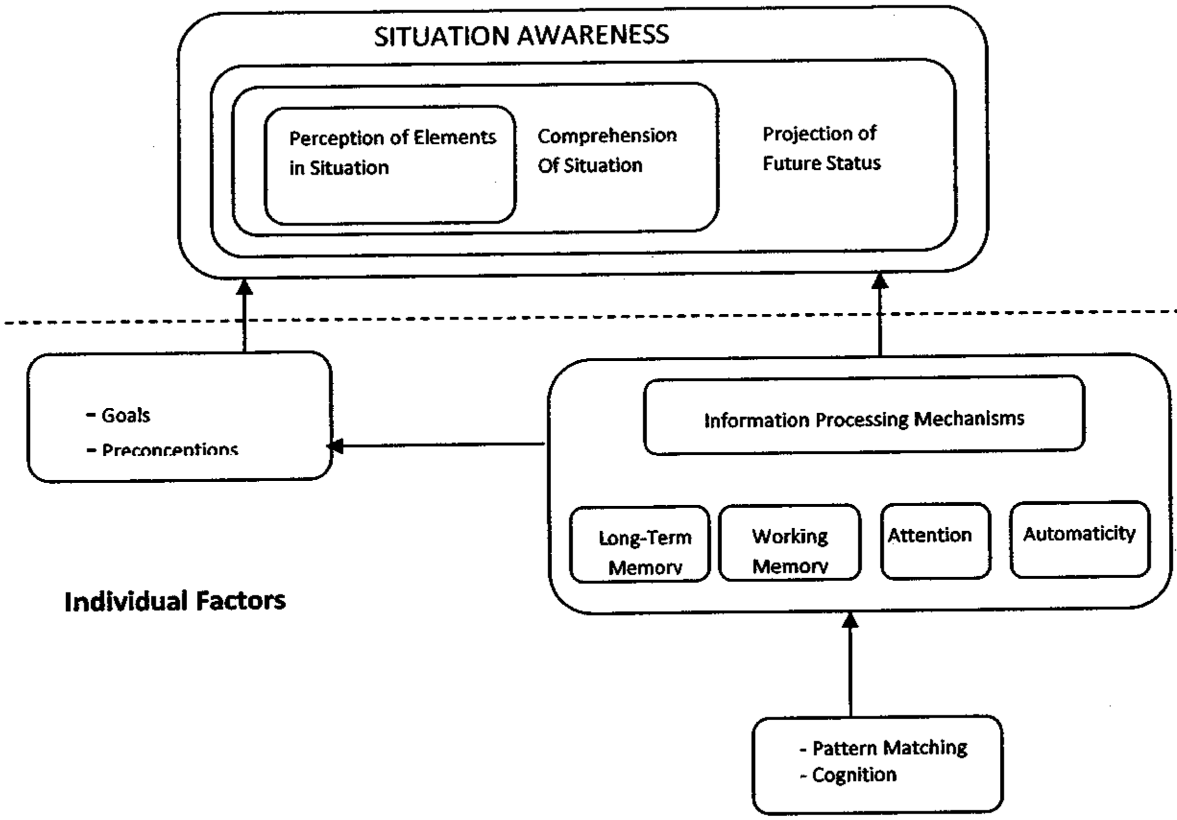

Figure 3: Schematic representation of Endsley's (2001) theory of situation awareness.

Level 1 SA (perception) is viewed as the most fundamental level of SA. In the cognitive domain, perception is a process which serves to "structure a description which can be manipulated for purposes of calculation about the world (and the self)" (Bregman, 1977, p. 251). Without perception of key events, an operator is most certain to make inappropriate and inaccurate decisions causing weaknesses in the system. Most studies employing the SA framework found varying percentages of error due to deficient perception (Endsley &Rodgers, 1998; Rodgers, Mogford & Strauch, 1999; Jones & Endsley, 1996). Level 2 SA (comprehension) involves a higher order of thinking and reasoning to include combining, interpreting, storing, and retaining information (Endsley, 2000). Comprehension describes one's ability to makes sense of the data perceived in Level 1. Level 3 (projection) is the highest attainable level of SA and is the ability to forecast, predict, and anticipate future events given the current level of understanding of a situation. Operators who achieve Level 3 SA, are those positioned to make the most accurate decisions and are typically considered skilled experts (Endsley, 2000).

Many environmental factors, as well as personal attributes, may affect one's level of SA (Endsley, 1988, 1995). Environmental factors proposed to influence SA include system compatibility, interface designs, stress and workload, level of complexity, and technology. Although environmental factors play a role in the development of SA, the focus of this proposed study is on the personal attributes related to SA in order to develop a best evidence predictor model of SA in Graduate Student Registered Nurse Anesthetists. Personal attributes believed to be important in SA include goals, preconceptions, long-term memory, working memory, attention, automaticity, pattern matching, cognition, and experience (Table 2). Researchers interested in studying SA have suggested the enhancement of SA at the individual operator level through education and training (Endsley & Bolstad, 1994; Gaba & Howard, 1995; Tirre, 1999).

Individual operator goals foster the development of SA by directing attention to salient elements in the environment in an effort to meet those goals (Endsley & Garland, 2000; Wright, Taekman & Endsley, 2004). In a complex environment, goals can either guide information selection and processing (top-down process) or new information can result in the formation of new goals (bottom-up process). The ability to move between

Table 2

Description of Personal Attributes Described in Endsley's Theory of SA

Personal Attributes	Relevance to Theory
Goals	Essential to the development of SA; operator actively seeks goal attainment
Preconceptions	Based on expectations from previous experiences; operator experiences what he expects to experience
Long-Term Memory	Long-term memory stores create schemata; schemata direct attention efficiently, help process chunks of information, and help project future conditions
Working Memory	Limited capacity places constraints on SA; necessary for combining and interpreting information; is supported by schemata in long-term memory
Attention	Accurate allocation is crucial for development of all levels of SA; directed toward information that is perceived to be important; highly influenced by environmental distractions
Automaticity	Developed with experience; reduces demands during physical tasks; may reduce responsiveness to non-routine stimuli
Pattern Matching	Used by experienced decision makers to recognize perceived information as belonging to a class of situations

top-down and bottom-up information processing is essential for SA (Endsley & Garland, 2000).

An operator's preconceptions have the power to influence his or her ability to acquire and maintain SA (Endsley & Garland, 2000). Preconceptions come from past experiences and existing mental models of the world. Preconceptions are self-expectations about what one should experience and have a profound impact on critical-thinking ability (Endsley & Garland, 2000; Leh, 2007). Endsley's theory of situation awareness posits that attention is directed and perceptions of information are influenced by one's preconceptions.

While preconceptions are essential for the development of SA, they also have the potential to derail performance in unfamiliar circumstances. Taylor, Endsley, and Henderson (1996) compared aviation teams assigned to develop problem-solving strategies during an event. One group was exposed to a preview of established expectations. This group, when compared to control, failed to demonstrate the same types of skills for active problem-solving and was less likely to act accordingly when events and situations did not follow the expected course. Preconceptions enable operators to experience what they expect to experience, potentially contributing to both favorable and unfavorable consequences (Endsley & Garland, 2000).

Long-term memory is essential to an operator's ability to form mental models of a challenging environment. Mental models can be important in the management of complex environments in that they reduce demands on working memory and direct attention to meaningful cues (Fracker, 1988; Sarter & Woods, 1991). Due to operator bias, mental models can just as well contribute to significant problems in the selection, interpretation, and processing of information. Mental models have the potential to hinder an operator's ability to think outside of the box (Eisner, 2005).

Working memory is essential to achieving Level 2 and Level 3 SA. It is important to note that although working memory plays a significant role in combining and interpreting information obtained from the environment, it has a fixed and limited capacity; a capacity which varies from person to person (Rouder, et al., 2008). Gugerty and Tirre (1997) discovered differences in working memory between those with high and low levels of SA. It is likely that working memory is the component that has the greatest impact on cognition (Baddeley, 1996).

Attention facilitates working memory. Simons and Chabris (1999) studied inattentional blindness for complex objects and events in dynamic environments in 192 undergraduate students. They learned that approximately half of the subjects failed to recognize an important but unexpected event while they were engaged in a primary monitoring task. The level of inattention directly correlated with the complexity of the primary monitoring task. The findings of this study suggest that unexpected events may be overlooked due to inattention. Murray and Byrne (2005) learned that individuals who excel at storing and processing information in working memory and who are proficient at switching attention are adept at problem-solving.

Automaticity refers to the ability to perform a task while putting little thought into it. It is achieved through learning, repetition, and practice (Endsley & Garland, 2000). Automaticity can either enhance SA or detract from it. During times of low intensity and routine practice, an operator can complete a task without much thought; that is, he or she performs automatically. Routine practice is reinforced by rules, protocols, clinical guidelines, and computer-based information systems (Egelhoff, 1992). During times of high intensity and unusual circumstances, however, that same operator may find it difficult to break the cycle of automaticity in order to respond effectively to the new, non-routine nature of the stimuli and, hence, all levels of SA may not be achieved.

Pattern matching and other cognitive processes are hypothesized as essential abilities for SA (Endsley & Garland, 2000). Through a review of the cognitive psychology, aviation, and human factors literature, Endsley and Garland (2000) found evidence that "experienced decision makers use pattern matching to recognize perceived information as a particular exemplar of a known class of situations" (p. 18). Endsley & Bolstad (1994) discovered a positive correlation between pattern matching skills and higher levels of SA in fighter pilots.

Hypotheses

In this study, there are three hypotheses based on the association between individual attributes and situation awareness as theorized by Endsley (1999) and as outlined in information processing theory. Memory, cognition, and automaticity will serve as the predictor variables and situation awareness as the criterion. The basic proposition is that memory, cognition, and automaticity are associated with situation awareness.

Hypothesis one (H_1): **There will be a direct positive linear relationship between memory and situation awareness in the GSRNA population.**

Hypothesis two (H_2): **There will be a direct positive linear relationship between cognition and situation awareness in the GSRNA population.**

Hypothesis three (H_3): **There will be a direct positive linear relationship between automaticity and situation awareness in the GSRNA population.**

Hypothesis four (H_4): **A combination of memory, cognition, and automaticity will produce a more predictive model of situation awareness in the GSRNA population than that produced by memory, cognition, or automaticity alone.**

In summary, situation awareness is a construct of interest in the study of complex systems such as aviation, air traffic control, military operations, nuclear power, and various branches of nursing and medicine, including anesthesia practice. Stemming from information processing theory, the theory of situation awareness has been employed, largely in the aviation industry, to understand how various levels of situation awareness impact performance, quality, and safety. Few studies, however, have confirmed or challenged Endsley's theory by examining the personal attributes that are hypothesized to predict SA. A detailed review of the relevant literature shows no research that examines predictors of situation awareness in anesthesia providers.

Training for Situation Awareness

In a complex environment, maintaining an adequate level of SA is an essential component of an operator's job (Endsley & Garland, 2000). Due to the important role SA has in the successful operation of many complex systems, the development and validation of training and education methods to enhance SA is critical. Endsley and Garland (2000) suggest approaches to SA training and education that include improving the design of systems to support SA and developing and amending team and individual training to enhance SA.

Generally speaking, very few training programs specifically address SA at the individual level; most focus on system design and factors that underlie SA (Endsley & Garland, 2000). Suggested methods of enhancing individual SA address the promotion of situation-specific mental models, the influence of preconceptions, and operator experience (Endsley & Garland, 2000). In congruence with Rasmussen's theory, Endsley and Garland (2000) conjecture that improvement of individual SA may be achieved through enhancing skill- and knowledge-based behaviors. Similarly, they suggest that high-order cognitive skills training which includes attention sharing, task management, information seeking and processing, and self assessment may be important for enhancing SA (Endsley & Garland, 2000). SA training programs incorporating frequent feedback are also valuable because they provide operators with opportunities to practice what they have learned and reflect on their performance (Boyd & Fale, 1983).

Bolstad and Cuevas (2005) aimed to improve individual SA in the military setting through cross training of team members. In this study, a subject who experienced a simulated complex situation from a role other than his or her own showed improved SA when compared to pre-intervention levels of SA. Although the study employed a small sample size (n=16), results show support for cross training as a mechanism to improve individual SA.

Gaba and Howard (1995) state that "anesthesia trainees as well as experienced practitioners would benefit if the element of situation awareness could be taught" (p. 28). To improve SA, they suggest training that includes enviro-scanning, the expanded use of checklists, directed allocation of attention, situation assessment, and processing of complex and abstract concepts. Chamet and O'Malley's (1987) research on the teaching and learning of language through the enhancement of long-term memory supports Gaba and Howard's (1995) conclusion. According to Chamet and O'Malley (1987), meta-cognitive strategies such as using advance organizers, planning for success, self-monitoring, and self-evaluation may improve long-term memory which, in theory, may enhance one's ability to develop SA. A thorough and current review of existing literature reveals no formal SA training programs or curricular models specific to nursing, medicine or anesthesia practice.

Chapter Summary

In an effort to improve quality and safety in complex systems, many industries have examined the construct of situation awareness. Much of the existing literature on situation awareness comes from the field of aviation psychology, air traffic control, and military operations with most sentinel articles dating in the 1990s. Given the limited research of SA in anesthesiology, work was done in this literature review to provide evidence of a significant link between situation awareness and human error, human error and complex systems, and complex systems and anesthesia practice to lay the groundwork and communicate a need for further study of SA in anesthesiology.

Two significant theories of human error were discussed. Reason (1990) believes errors occur when active failures, also named triggers, come into contact with latent factors; dormant and faulty mechanisms living within a system. Reason (1990) provides examples of latent factors as fatigue, improper training, and scheduling problems. It is conceivable that inadequate SA may also be a latent factor within a system. Rasmussen

(2003) theorizes that error is a product of human adaptation to a work environment. Under stable working conditions, one develops routine ways of doing things and adaptation is relatively easy. Effective work performance in dynamic and complex work conditions, however, necessitates continuous and adequate awareness of the environment and of all possible alternative strategies for decision-making and problem-solving (Rasmussen, 2003). Both theories, either directly or indirectly, identify adequate situation awareness as an essential skill to reduce the incidence of error.

In this chapter, information processing theory and Endsley's theory of SA were presented as the theoretical underpinnings of this study. Many of the personal attributes that are considered to be major contributors to SA were described and analyzed. Individual attributes found to have an effect on SA include personal goals, preconceptions, memory, attention, automaticity, cognition, and experience. Where applicable, evidence from the discipline of cognitive psychology was presented to improve understanding of how these attributes influence SA. Most research aiming to improve operator SA suggests methods directed at improving the design of systems and team training.

Generally speaking, few studies outside of aviation employ the framework presented in Endsley's theory of situation awareness to empirically study SA in complex systems, although many confirm the importance of SA as a key component in quality and safety improvement and effective performance. Because the specialty of anesthesia is first and foremost concerned with quality, safety, and effective performance, especially in the face of changing patient demographics, advances in technology, and changes in the anesthesia workforce, this research examining predictors of SA in GSRNAs is important and timely. If a meaningful predictor model of SA in GSRNAs is found, this study has the potential to improve the efficiency and effectiveness of education and training on the preparedness of future anesthesia providers to handle the complexity that characterizes the practice and delivery of anesthesia. This study also seeks to add to the current body of knowledge surrounding SA and its contributing factors.

The specific objectives of this study are to determine a) the extent to which memory, cognition, and automaticity are related to situation awareness, b) the extent to which any relationship amongst memory, cognition, and automaticity mediates their relationship with situation awareness, and c) the extent to which Endsley's theory of situation awareness is supported in the GSRNA population.

CHAPTER 3: METHODOLOGY

Since the beginning of the patient safety movement in the 1980s, researchers have been trying to identify and classify major contributors to medical error which endanger the lives of tens of thousands of patients each year across our nation (Kohn, Corrigan, & Donaldson, 1999). Many studies have been successful at recognizing human factors as significant causes of error within our health care system which includes the practice of anesthesia (Gaba & Howard, 1995; Cooper, Newbower, & McPeek, 2002; Bowdle, 2003; Aitkenhead, 2005). Since the system of anesthesia delivery is burdened with complexity, it is essential that anesthesia providers possess adequate levels of situation awareness. Future research examining individual attributes that contribute to one's ability to develop situation awareness has been suggested to better understand this construct and to develop education and training programs which may enhance situation awareness (Endsley & Bolstad, 1994; Bolstad & Cuevas, 2005).

Guided by Endsley's theory of situation awareness, the purpose of this study was to provide nurse anesthesia educators with a best evidence predictor model of situation awareness in Graduate Student Registered Nurse Anesthetists (GSRNAs) for curricular implementation by: a) identifying a predictor model that describes the relationship between situation awareness and memory, cognition, and automaticity in GSRNAs, and

b) further establishing and testing the validity of Endsley's theory of situation awareness in the GSRNA population.

Findings from this study have the potential to positively influence the selection and training of GSRNAs. As individual attributes were found to be associated with situation awareness, nurse anesthesia educational programs can choose to develop curricular strategies to cultivate and enhance these characteristics thereby potentially preparing a safer and more adept practitioner. Additionally, this study may provide foundational support for research directed at assessing the effectiveness of high-fidelity simulated operating room environments in promoting situation awareness in GSRNAs. The central hypotheses of this study predicted that higher scores on measures of memory, cognition, and automaticity will be associated with higher levels of SA.

The objectives of this research study were to determine a) the extent to which memory, cognition, and automaticity are related to situation awareness, b) the extent to which any relationship amongst memory, cognition, and automaticity mediates their relationship with situation awareness, and c) the extent to which Endsley's theory of situation awareness is supported in the GSRNA population. A summary of the study purpose, objectives, and research hypotheses is provided in Table 3.

This chapter describes the research methods and statistical procedures employed to address the research question: Is there a relationship between situation awareness and memory, cognition, and automaticity in graduate student registered nurse anesthetists? The research design, population and sampling methods, inclusion and exclusion criteria,

Table 3

Summary of Study Purpose, Objectives, and Research Hypotheses

Purpose	Objectives	Research Hypotheses
1) To provide nurse anesthesia educators with a best evidence predictor model of situation awareness in Graduate Student Registered Nurse Anesthetists (GSRNAs) for curricular implementation	a) To determine the extent to which memory, cognition, and automaticity are related to situation awareness	H_1: There will be a direct positive linear relationship between memory and SA.
		H_2: There will be a direct positive linear relationship between cognition and SA.
		H_3: There will be a direct positive linear relationship between automaticity and SA.
	b) To determine the extent to which any relationship amongst memory, cognition, and automaticity mediates their relationship with situation awareness	H_4: A combination of memory, cognition and automaticity will produce a more predictive model of situation awareness than that produced by memory, cognition, or automaticity alone.
	c) The extent to which Endsley's theory of situation awareness is validated in the GSRNA population.	N/A

predictor and criterion variables, variable measures, hypotheses, data collection and analysis procedures, and study limitations are presented.

Research Design

A descriptive, non-experimental, cross-sectional, correlational design was used to study the relationship between situation awareness and memory, cognition, and automaticity, in GSRNAs (Figure 4). Use of descriptive research serves to examine the associations among the study's variables rather than discover cause and effect relationships (Dulock, 1993; Polit & Beck, 2004). A correlational design allows for a determination of the extent to which the variance associated with situation awareness could be attributed to memory, cognition, or automaticity or any combination thereof. For this study, it was practical and economical to use a cross-sectional approach since time-related processes and comparisons over time are not being studied (Polit & Beck, 2004).

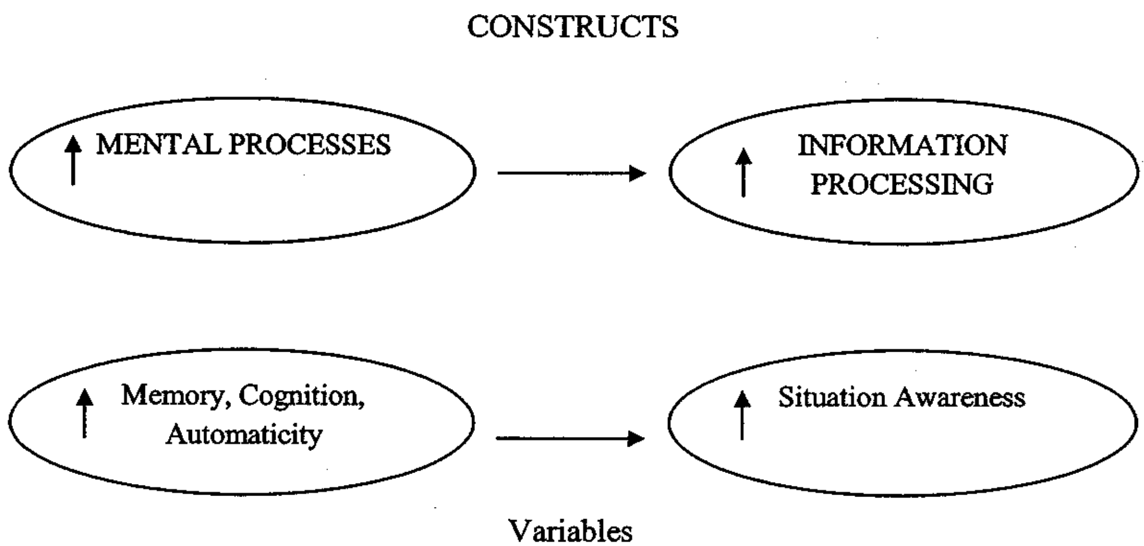

Figure 4: A description of constructs and variables presented in Bacharach's (1989) framework.

Population, Recruitment, and Sampling Methods

The target population being addressed by this study was GSRNAs in the United States (US). The accessible population included GSRNAs enrolled in accredited nurse anesthesia programs from a convenience sample of three large US universities: Virginia Commonwealth University, Richmond, Virginia; Louisiana State University, New Orleans, Louisiana; and Samford University, Birmingham, Alabama. The university programs used in this study comprised a convenience sample which was selected at the American Association of Nurse Anesthetists (AANA) Assembly of School Faculty in February 2008. A comparative description of the selected university programs is offered in Table 4.

After Institutional Review Board (IRB) approval, subjects from the junior and senior classes of each university were randomly selected from a pool of volunteers in the accessible population using a stratified random sampling method. There were 111 subjects enrolled in the study. Due to 36 missing values on the criterion measure, which were determined to be not missing at random, all 36 cases were dropped leaving a sample size of 75. On further investigation of the data, four more cases were evaluated as outliers and dropped from the analysis. A final sample size of 71 subjects was determined to have sufficient power, based on a medium population effect size, with α=.05, and β=.20 (Polit & Beck, 2004; Tabachnick & Fidell, 2007; Soper, 2009).

Stratified random sampling on year and university from the volunteer pool was useful since the accessible population was geographically dispersed and the researcher

Table 4.

Comparative Description of Nurse Anesthesia Programs chosen for the Study.

	VCU	SAMFORD	LSU
Program Size	100 students; 3 classes	178 students; 3 classes	130 students; 3 classes
Location	Richmond, VA	Birmingham, AL	New Orleans, LA
Public/Private	Public	Private	Public
Student/Faculty Ratio	17:1	20:1	43:1
Content Delivery Method	Traditional; Distance	Traditional	Traditional
Demographic Information	Avg Age: 28 M:F 1:3 W:NW 20:1	Avg Age: 27 M:F 1:4 W:NW 25:1	Avg Age: 29 M:F 2:3 W:NW 21:1

aimed to have equal representation from each class at each university (Hulley et al., 2007). Two weeks after distributing flyers describing the study to junior and senior nurse anesthesia students at each university, an on-site research liaison scheduled a meeting for both classes on each campus to answer questions and determine an approximate number of volunteers. All potential subjects were assured that participation was voluntary and that participation would in no way affect their academic standing. On the initial day of data collection on campus, the researcher asked volunteers from each stratum to blindly draw a lettered number out of a box. The lettered number represented the university and the class.

For instance, there were 25 volunteers in the junior class at VCU. Each volunteer drew a lettered number from VJ01 through VJ25 from a box. The volunteers were instructed to remember their number and record their name and corresponding lettered number on the confidential sign-up sheet. The sign-up sheet was placed into a sealed envelope and labeled confidential. At that time, lettered numbers VJ01 through VJ25 went back into a box and 20 subjects were chosen at random by the researcher. In strata where the number of volunteers was less than 20, all volunteers were enrolled into the study to maximize sample size. The multi-university sample ideally represented the larger US GSRNA population which was important to the generalizability of the study findings.

Variables

The three predictor variables chosen for this study were based on Endsley's theory of situation awareness and a thorough review of the SA, cognitive psychology, and anesthesiology literature. The predictor variables included memory, cognition, and automaticity. Although several variables, according to Endsley (2000), are hypothesized to predict situation awareness, memory, cognition, and automaticity were examined in this study largely because of their potential to be addressed by curricular strategies in nurse anesthesia education.

Strategies designed to enhance working memory, such as mnemonics, are described in the cognitive literature (Ashcraft, Donley, Halas, & Vakali, 1992; Baddeley, 1996; Klingberg, Forssberg, & Westerberg, 2002). Mnemonic strategies refer to a "specific reconstruction of target content intended to tie new information more closely to the learner's existing knowledge base, and therefore, facilitate retrieval" (Scruggs & Mastropieri, 1990a, p. 271). Mnemonics serve as a reminder for well-learned information, to help overcome lapses in memory, to assist in activities performed in particular sequences, to anchor facts, and as a guide when written information is unavailable (Belleza, 1983). Mnemonic strategies can be explored in the anesthesia setting to serve as quick references and important resources in the face of a crisis.

Exercises such as cognitive task analysis (CTA) have been used in the training of operators of complex environments to develop the cognitive skills necessary to manage the uncertainty, risk, and temporal elements of an ensuing crisis. Kaempf, Klein, Thordsen, & Wolf (1996) employed CTA by conducting critical incident interviews of active-duty naval officers to analyze the officers' thought processes, organization strategies, and patterns of decision-making. Similarly, the process of CTA could be used by nurse anesthesia educators in the development of crisis scenarios with a goal of developing cognitive skills thereby potentially enhancing situation awareness.

From 1990 to 1997, field studies of adverse military events were performed in the Tactical Decision Making under Stress (TADMUS) program sponsored by the Office of Naval Research (Collyer & Malecki, 2006). The purpose of the program was to examine critical incidents occurring in the military setting with a goal of enhancing performance in high-stress operational environments through the development of training and human factors technologies. The researchers concluded that training which incorporates the improvement of automaticity through repetitive practice of low-level skills, has the potential to improve performance under high-stress conditions by freeing the cognitive resources necessary for higher level decision-making (Cohen, Freeman, & Thompson, 2006). Similarly, training programs in schools of nurse anesthesia may employ teaching methods which involve the repetitive practice of skills such as central venous cannulation, endotracheal intubation, and monitor interpretation. Such repetitive practice could enhance automaticity of these lower-level skills, leaving available higher-level cognitive resources necessary to comprehend and manage the unfamiliar and complex nature of an anesthetic crisis.

Although a review of the literature revealed no study examining the relationship between age and gender and situation awareness, age and gender were included in this study as covariates. The inclusion of these covariates a) removed age and gender bias that would have otherwise eliminated the ability to generalize the results of the study, and b) helped to establish a deeper understanding of what contributes to situation awareness in GSRNAs. The criterion variable was situation awareness. All variables and their measures are included in Table 5.

Measure of Working Memory

Working memory has been compared to an executive's desktop (Logan, 2004). It is the epitome of simultaneous processing and storage and "keeps one thing in mind, while doing another" (Logan, 2004, p. 219). Working memory is essential to achieving Level 2 and Level 3 SA in challenging environments (Endsley & Garland, 2000). The number of items that can be accurately recalled from working memory normally ranges

Table 5

Description of Variables and Measures

Variable	Type	Measure	Type of Data
Memory	Predictor	Score on Digit Span Test	Continuous
Cognition	Predictor	Raven's Standard Progressive Matrices Test	Continuous
Automaticity	Predictor	Length of ICU Experience	Continuous
Age	Covariate	Age in Years	Continuous
Gender	Covariate	0 = Male 1 = Female	Dichotomous
SA	Criterion	Score on WOMBAT-CS	Continuous

from three to seven and its capacity varies from person to person (Logan, 2004; Barrett, Tugade, & Engle, 2004). Digit Span, a subtest of the revised Wechsler Adult Intelligence Scale (WAIS-III), is commonly used as a measure of working memory and was used as a measure of working memory in the current study (Groth-Marnat, 1997; Kaufman & Lichtenberg, 1999; Ryan & Smith, 2003; Sattler & Satlofske, 2001).

Digit Span requires the subject to repeat numbers forwards then backwards as read aloud by an examiner. The examiner starts with calling out two random numbers;

each number at one second intervals. With each successful repeated sequence another random number is called, this time with one additional random number. The series continues until the subject fails to repeat the number accurately and a quantitative score is given based on number of correct responses (Wechsler, 1997). .

The WAIS-III was standardized on a highly stratified sample of 1,800 US subjects, broken down into nine different age groups ranging from 16 to 74 years of age. Equal numbers of men and women were used, as were white and nonwhite subjects. The sample was further broken down into four geographic US regions and six occupational categories. There was also an attempt to balance urban and rural subjects (Wechsler, 1997). The mean intelligence quotient (IQ) for each age group on this test was 100, with a standard deviation of 15.

The internal consistency of Digit Span was examined by Hall and Toal (1957) who reported a moderate Cronbach's coefficient alpha, a measure of item consistency or reliability, of .647. This moderate internal consistency suggests a mature scale where each item is important to the construct of short term memory. A computer version of Digit Span was administered in this study to all research subjects at each campus simultaneously after instructions were provided and subjects confirmed understanding of the examination. Scores were awarded based on the correct number of digits repeated and then recorded by the researcher on the Self-Report Data Sheet

Measure of Cognition

Endsley & Garland (2000) suggest that cognitive processes such as pattern matching, conscious analysis, story building, and mental simulation, all may be used by operators at various times to develop situation awareness. Spearman (1904) hypothesized that cognitive and intelligent behavior is generated by a quality within the human brain. He referred to this quality as the general factor, represented as *g*, and derived an intelligence theory through factor analysis which demonstrates that individuals' scores on all cognitive examinations are positively correlated with *g*.

Raven's Standard Progressive Matrices (SPM) (1989) was designed to measure one's ability to reason by analogy, independent of language and education level. Raven's SPM is a valid and reliable measure of Spearman's *g* in subjects aged 6 years to adult (Raven, 1989). More specifically, Raven's SPM is used as an assessment of eductive ability, or one's capacity to think clearly and make sense of complex situations (Raven, 1989).

Raven's SPM is a 45-minute, self-administered paper and pencil examination which consists of 60 items separated into five sets of 12 items each. The items contain a figure with a missing piece. Pictures of alternative pieces that may complete the picture are presented below the referent figure, only one of which is correct. Each set involves a different principle for discovering the missing piece and within any one set, the problems are progressively more difficult. A raw score is calculated to evaluate performance which may be converted to a percentile rank if desired. Internal consistency test-retest correlations range from a low of .46 for an eleven-year interval to a high of .97 for a two-day interval. The median test-retest value is .82. The test-retest coefficient's for the SPM for those < 30 years , 30-39 years, 40-49 years, and 50 years and over are .93, .88, .87, and .83 respectively. Construct validity of the SPM was determined by the same factor analysis methods used to define *g* initially. Concurrent validity coefficients between the SPM and the Stanford-Binet and Wechsler scales range between .54 and .88, with the majority of coefficients in the .70's and .80's (Raven, 1998).

Raven's SPM was administered to all study subjects on-site by the researcher. Test booklets, answer keys, and sharpened pencils were distributed and instructions for the examination were provided. Subjects were reminded to record their subject numbers on the answer sheet and were allowed 45 minutes for completion. Upon conclusion of the test, subjects deposited the test booklets and answer sheets in a box located at the front of the room.

Measure of Automaticity

Automaticity refers to the ability to perform a task while putting little thought into it and has been described as the learned advantage of an expert (Perry, 2003). Automaticity is achieved through learning, repetition, and practice and reduces demands on attentional and cognitive resources; automaticity is often gained through experience (Endsley & Garland, 2000). As a prerequisite to entry into all anesthesia programs in the US, GSRNAs are required to have at least one year's nursing experience in an acute care setting, usually an intensive care unit (ICU). Since the complex and rapidly-changing nature of nursing in the ICU requires a keen awareness of a multitude of patient conditions and environmental situations (Clochesy, 1996), the length of time working in an ICU as a professional nurse will theoretically enhance automaticity in responses to tasks in this complex environment. Automaticity is hypothesized to contribute to SA (Endsley & Garland, 2000).

The automaticity variable in this study was measured by self-report on the Self-Report Data Sheet as collective whole months, rounded to the nearest month, working as a registered nurse in an ICU setting prior to the start of the nurse anesthesia program. It was hypothesized that the longer a subject has worked in an ICU setting prior to admission into the nurse anesthesia program, the higher the situation awareness score he or she would acquire.

Measures of Demography

Age and gender were used in the statistical analysis as blocking variables to eliminate their impact on the generalizability of the results. Data describing age and gender were reported on the Self-Report Data sheet by each subject. Age was reported in years, rounded to the closest year. Subjects were asked to record their gender on the Self-Report Data Sheet as male or female. By examining the relationships between age and gender and situation awareness, the researcher aimed to gain a better understanding of the contribution each of these demographic variables made to the development of situation awareness in GSRNAs.

Measure of Situation Awareness

Situation awareness is a difficult construct to measure because it lends itself to both subjective and objective interpretation (Endsley & Garland, 2000). Most available measures assess situation awareness in the context of a specific discipline or scenario. Situation awareness has been measured in air traffic control systems, self-defense arenas, military operations, aviation, simulated medical environments, and command and control environments (O'Hare, 1997; Endsley & Bolstad, 1994; Jones, 1997; Wright & Taekman, 2004).

The variable of situation awareness was measured in this study by the Wondrous Original Method for Battle Airmanship Testing in Complex Systems (WOMBAT-CS) (LaRoche, Corl, & Roscoe, 2001). The WOMBAT-CS Situation Awareness and Stress Tolerance Test is a modern computer-based evaluation of situation awareness designed to measure an operator's ability to scan a simulated complex environment for multiple sources of information, prioritize requisite tasks, and entertain viable alternative decisions and actions (Roscoe & Corl, 1987; LaRoche, Corl, & Roscoe, 2001). The WOMBAT-CS is an electronically controlled device that gathers data based on the operator's responses and input via two neighboring joysticks. The control console which houses the joysticks is connected to a laptop computer by way of a standard parallel connection. The size of the console is comparable to that of a standard computer keyboard. The program's software collects and reports user scores.

WOMBAT-CS embodies several demands and constraints from the study subject (LaRoche, 2001). Individual tasks combine target tracking, pattern recognition, spatial orientation, and short-term memory. The test is culture-free in that it has no resemblance to any "real-world vehicle control" (Roscoe, 1993, p. 49). Due to its unique design, a subject's prior skills do not directly affect test performance. This is a self-administered, 50-minute evaluation which provides a quantitative score of situation awareness upon its completion (LaRoche, 2001).

The WOMBAT-CS is designed as a tool for measuring situation awareness in complex system operators such as "pilots, air traffic controllers, ship and train operators, anesthetists, nurses, paramedics, 9-1-1 dispatchers, nuclear-plant operators, ... [and] anyone in charge of complex operations involving multiple concurrent inputs and response alternatives" (LaRoche, Corl, & Roscoe, 2001, p. 1). High situation awareness scores on the WOMBAT-CS rely on one's ability to identify what is important now (perception) and in the long run (projection), prioritize effectively, avoid preconceived assumptions and subjective biases, remain vigilant, ignore irrelevant distractions, tolerate frustration during poor performance, cope with the stress of a high workload, cope with boredom of routine tasks, and resist complacency during periods of low workload (LaRoche, Corl, & Roscoe, 2001).

A subject's overall WOMBAT-CS score is determined by the extent to which he or she masters three-dimensional tracking, orientation, pattern recognition, and short-term memory activities (O'Hare, 1997). In order to score well, the subject must continuously monitor peripheral indicators to follow the shifting priorities of various tasks as indicated by their level of difficulty and to recognize when the system goes into failure mode which then requires immediate termination of one activity in favor of another (LaRoche, Corl, & Roscoe, 2001). These combined abilities are indicative of the subject's situation awareness.

To determine the validity of the WOMBAT-CS as a quantitative measure of situation awareness and a predictor of exceptional performance in aviation tasks, O'Hare (1997) assessed the relationship between WOMBAT-CS scores and independent measures of age, occupation, computer experience, computer game playing, digital recall, and pattern recognition in a two-part study. In the first part of the study, O'Hare (1997) sampled 24 men, ages 26 to 62 years with different occupations who were randomly recruited from the community. O'Hare (1997) compared the results of each constituent part of the WOMBAT-CS (three-dimensional tracking, orientation activities, pattern recognition, and short-term memory) to commensurate tests of the Walter Reed Performance Assessment.

O'Hare (1997) found that scores on the WOMBAT-CS were significantly correlated with computer game experience in the first ten minutes of the test r=.64, p<.001, decreasing to r=.47, p<.05 at the conclusion of the test. Likewise, pattern recognition scores correlated significantly with WOMBAT-CS scores: r=.59, p<.01 after 10 minutes, and r=.57, p<.01 at the conclusion of the test.

Stepwise regressions were then performed using initial and final WOMBAT-CS performance as criterion variables. The model for final WOMBAT-CS scores contained two variables: pattern recognition ability and computer-game experience. Since standard regression analyses do not provide exact estimates of the proportion of variance in the criterion variables accounted for by each of the predictor variables, O'Hare (1997) computed the uniqueness index for each variable. The uniqueness index (U) is defined as "the squared semipartial correlation between a criterion variable and the predictor variable of interest, after statistically controlling for the variance that the predictor shares with the other predictors" (Hatcher & Stepanski, 1994, p. 432). O'Hare (1997) reported the uniqueness index as $U = R^2(\text{Full}) - R^2(\text{Reduced})$ and learned that the WOMBAT-CS "measures some ability over and above those measured by the battery of component ability measures" (p. 549). This is the unique variance shared between the pattern recognition ability and computer-game experience variables. On the uniqueness index, both computer game experience, $F(1,10) = 13.07$, $p < .01$, and pattern recognition ability, $F(1,10) = 14.27$, $p < .01$, contributed significantly to the variance in initial WOMBAT-CS performance. These two variables along with mental rotation ability accounted for 51% of the variance in initial WOMBAT-CS scores. After 50 minutes of WOMBAT testing, however, pattern recognition ability was the only variable to account for significant variance in WOMBAT scores $F(1,10) = 7.07$, $p < .05$.

From this first study, O'Hare concluded that performance on the WOMBAT-CS is not just a function of age, employment, computer experience, computer game experience, or abilities on any particular psychometric measure. This premise laid the groundwork for the second part of the study to examine WOMBAT-CS performance in skilled aviators.

In this follow-up study, O'Hare (1997) recruited eight elite pilots, six novice pilots, and twelve control participants (n=26). He posited that:

> If, as theorized, the most important contributor to SA lied in the ability to manage the attentional demands of complex situations, and if the WOMBAT task is a valid measure of such an ability, then one would expect to find that successful pilots will perform better on the WOMBAT task than matched controls and that elite pilots who have demonstrably superior skills to similarly qualified pilots will perform even better. (p. 547).

O'Hare (1997) found that the eight elite pilots had higher SA scores than the six novice pilots and that the six novice pilots scored higher than those in the control group.

Chi-square confirmed a significant difference between the observed and expected frequencies for the three groups ($\chi^2(4) = 11.37$, p= .05). Phi coefficient supported these group differences (0.77, df = 4, p<.05). O'Hare's (1997) two-part study demonstrated that the WOMBAT-CS was a valid measure of underlying abilities related to pilot performance. In 1997, Roscoe reported a rank difference correlation of .88 on two separate administrations of WOMBAT-CS to the same group. This represents a high level of reliability based upon a test-retest sequence (Cain, 2001).

In his study of 54 aviation students, Cain (2001) employed the WOMBAT-CS to study the relationships between metacognition, self-efficacy, and educational and/or flight experience and situation awareness in an effort to add to SA's conceptual and theoretical development. This study indicated that while there was no significant association between metacognition and SA or between self-efficacy and SA, there were significant correlations between metacognition and self-efficacy (r=.576, p<.01) and between flight hours and SA (r=.354, p<.01). While Cain (2001) recommends that the WOMBAT-CS be studied against other measures of SA to establish further predictive validity, he suggests that the tool provides a benign approach for testing a subject's level of SA and stress tolerance prior to engaging with the actual complex environment.

Prior to data collection and following the test administration protocol, the WOMBAT-CS was administered to two certified registered nurse anesthetists (CRNAs) currently practicing anesthesia in Richmond, Virginia and an Information Technologist working in a nurse anesthesia department. Within two weeks of the initial WOMBAT-CS test, these subjects took the WOMBAT-CS test a second time under the same environmental conditions. A Pearson's Product Moment Correlation coefficient of r=.76 was calculated between the first WOMBAT-CS scores and the second WOMBAT-CS scores. Reliability coefficients above .70 are considered acceptable under most normal conditions (Polit & Beck, 2004). Aero Innovations, Inc., the manufacturer of the WOMBAT-CS, report similar correlation coefficients between first time WOMBAT-CS test scores and subsequent WOMBAT-CS test scores (r=.88).

Data Collection

Data collection occurred in sequential order from one university to the next: first, Virginia Commonwealth University, second, Samford University, and third, Louisiana State University. VCU was chosen first because the researcher was able to be on site during the entire data collection period to oversee and manage this process before implementing it at distance sites. The data collection process occurred as follows at each site. After IRB approval and on day one of data collection, all volunteers met with the researcher in a classroom type setting. An overview of the project including testing procedures and data collection methods was presented and consent forms were discussed and completed.

Emphasis was placed on the importance of each participant to read the WOMBAT-CS Candidate's Manual before actual testing. Each participant was given a thorough explanation of the WOMBAT-CS including how it works, the significance of each parameter, and how it scores performance. The participants were assured that their scores were confidential and that they could stop the test at anytime with no adverse consequences. At the same time, each participant was advised of the importance of motivation in successfully completing the WOMBAT-CS. They were advised that it is normal to take as long as 20 minutes before feeling comfortable with the controls and the operation of the program (LaRoche, Corl, & Roscoe, 2001). Therefore, subjects were encouraged to remain steadfast and to do their absolute best for as long as possible.

Pilots taking the WOMBAT-CS are usually doing so for employment selection which provides a high level of motivation (LaRoche, Corl, & Roscoe, 2001). To provide commensurate motivation to participants in this study, a $5 coffee card was offered to all study volunteers and a $10 bookstore gift card was offered to all subjects completing the study. An opportunity for subjects to ask questions and discuss concerns was provided.

A packet of project materials was distributed to the study subjects on-site. Each packet included an overview of the study, the Self-Report Data Sheet, the Raven's SPM test booklet and answer sheet, a sharpened pencil, and a copy of the WOMBAT-CS Candidate's Manual. Subjects were instructed to enter their subject number on the Self-Report Data Sheet and the Raven's SPM answer sheet. Subjects were given 20 minutes to complete the Self-Report Data Sheet followed by 45 minutes to complete the Raven's SPM exam. They were instructed to place the completed materials into the original envelope and to deposit the envelope into a designated confidential drop-box in the testing area.

Digit Span

On the afternoon of the initial meeting with the researcher, subjects were gathered in the computer lab at their respective universities to commence Digit Span testing. Once all volunteers arrived in the computer lab, Digit Span was administered to all subjects simultaneously to maximize efficiency. Volunteers had the opportunity to ask questions before beginning the exam and were instructed to remain quiet following the exam until notified by the researcher. Digit Span testing time ranged between 20 and 30 minutes, depending on the number of subjects being tested. Scores on Digit Span were recorded as number of digits remembered correctly. The scores were taken from the computer screen and recorded by subject number onto the project data spreadsheet by the researcher.

WOMBAT-CS

Once testing packets were returned and Digit Span testing was completed, WOMBAT-CS testing sessions were scheduled and commenced over the three to four weeks following the initial project meeting. The WOMBAT-CS units were located in quiet environments resembling small offices so that the participant would be protected from noise and other interruptions. All questions from subjects regarding WOMBAT-CS testing were answered and a sample test was demonstrated. There were two WOMBAT-CS units available for testing at each site with each test taking approximately 60 minutes (a 10 minute warm-up and hands-on practice session, followed by a 50 minute examination). Anywhere from 0 to 8 subjects were accommodated per day. During WOMBAT-CS testing at all sites, there was no malfunctioning of the equipment. In an effort to promote smooth operation of the WOMBAT-CS system and to streamline the data collection process, an information technologist consultant was available either in person or by phone during the hours in which WOMBAT-CS sessions are scheduled.

The WOMBAT-CS software retained subjects' scores and a manual record of scores was also kept by the researcher or on-site research liaison using the lettered-number subject identifier. The software captured six scores total: tracking score, figure rotation score, quadrant-location score, digit-canceling score, total bonus score, and overall SA score (see Table 6). WOMBAT-CS overall SA scores were automatically stored in individual electronic participant files by subject number.

Table 6

Description of WOMBAT-CS Scores

WOMBAT-CS Score	Description
Tracking Score	Tracking Worth multiplied by the Tracking Performance. Dependent upon tracking performance and frequency of engagement in bonus tasks.
Figure Rotation Score	Bonus points earned from the Figure-Rotation bonus task.
Quadrant-Location Score	Bonus points earned from the Quadrant-Location bonus task.
Digit-Canceling Score	Bonus points earned from the Digit- Canceling bonus task.
Total Bonus Score	Sum of the points earned in Figure Rotation, Quadrant-Location, and Digit-Canceling.
Overall Score	Score that should be used for overall assessment of performance on WOMBAT-CS.

At the end of the 50 minute WOMBAT-CS testing session, the program congratulated the testee and notified him or her that the exam was complete. On an occasion where a testee chose to terminate the exam before the 50 minute session was complete, a projected overall SA score was calculated by the WOMBAT-CS software based on performance and time spent on the exam. The projected overall SA score was then used in data analysis. The described testing protocol was consistent with the administration protocol advised in the WOMBAT-CS testing manual (LaRoche, Corl & Roscoe, 2001).

Research Hypotheses

It was hypothesized that higher scores on measures of memory, cognition, and automaticity would be associated with higher SA scores on the WOMBAT-CS. The research hypotheses were:

Hypothesis one (H_1): **There will be a direct positive linear relationship between memory and situation awareness in the GSRNA population.**

Hypothesis two (H_2): **There will be a direct positive linear relationship between cognition and situation awareness in the GSRNA population.**

Hypothesis three (H_3): **There will be a direct positive linear relationship between automaticity and situation awareness in the GSRNA population.**

Hypothesis four (H_4): **A combination of memory, cognition, and automaticity will produce a more predictive model of situation awareness in the GSRNA population than that produced by memory, cognition, or automaticity alone.**

Statistical Analysis

All data collected from each subject at each university was recorded onto the project data spreadsheet, entered into SPSS, and cleaned in preparation for statistical analysis. Descriptive statistics were calculated on all measures and examined through SPSS FREQUENCIES. Data transformations were made from an analysis of the amount and pattern of missing data. The analysis used SPSS Missing Values Analysis (MVA) (Tabachnick & Fidell, 2007). A correlation matrix was developed to examine relationships among the data.

Sample variable distributions using untransformed variables were examined for normality, homogeneity of variance, and univariate outliers (SPSS REGRESSION, plot of residuals). An analysis of residuals was used to detect and eliminate multivariate outliers (SPSS REGRESSION, χ^2 distribution). These analyses resulted in data transformations in order to comply with statistical model assumptions as discussed in Chapter Four. As outliers were detected, erroneous data entry and overlooked missing values specifications were corrected (Tabachnick & Fidell, 2007). Linearity and homoscedasticity were evaluated through SPSS GRAPH. Criteria to detect and account for multicollinearity were applied to the regression analysis.

Objective A (H_1, H_2, H_3)

To test the extent to which there was a relationship between and among memory, cognition, automaticity, and SA, a Pearson correlation coefficient (r) for each relationship was determined. Pearson correlation coefficients can be calculated with SPSS software and are useful when a researcher is interested in examining the direction and magnitude of the linear relationship between variables. As a guideline, an r value between 0.2 and 0.4 indicates a mild association; a value of 0.4-0.7 represents a moderate association; and a value of 0.7-1.0 describes a strong association (Myles & Gin, 2000). A coefficient of determination (r^2) was also calculated for each relationship to determine the degree to which a change in one variable influenced the change in another (Myles & Gin, 2000).

Objectives B (H_4) and C

To test a) the extent to which any relationship amongst memory, cognition, and automaticity mediates their relationship with situation awareness, and b) the extent to which Endsley's theory of situation awareness is supported in the GSRNA population, a statistical (stepwise) linear regression was performed with the order of entry of predictor variables based solely on statistical criteria (Tabachnick & Fidell, 2007). The stepwise approach allowed the researcher to determine whether the addition of differences in cognition and automaticity improved prediction of situation awareness in GSRNAs beyond that afforded by differences in memory alone (Myles & Gin, 2004; Tabachnick & Fidell, 2007).

It is essential to assess the importance of all independent variables in statistical regression (Tabachnick & Fidell, 2007). The correlation matrix produced from SPSS REGRESSION described the total relationship of memory, cognition, and automaticity to situation awareness as well as the correlations of memory, cognition, and automaticity with each other. To appreciate the unique contribution of each predictor variable to the total variance in situation awareness, the squared semi-partial correlation (sr_i^2) was computed and examined. In this statistical regression, sr_i^2 described the proportion of the variance in situation awareness with the addition of each predictor variable (Tabachnick & Fidell, 2007). Also, beta (β) was evaluated for memory, cognition, and automaticity to indicate the relative weights of the variables in the regression equation and to determine their significance in the overall regression model (Tabachnick & Fidell, 2007). The goal was to establish the best model for prediction of situation awareness in GSRNAs. The full model was $(SA)' = A + B_m(MEMR) + B_c(COGN) + B_a(AUTO)$, where MEMR represented memory, COGN represented cognition, and AUTO represented automaticity. Generalizability was demonstrated against the statistical hypothesis that the variance due to each predictor variable will be zero with 95% confidence. Additionally, an F-statistic and t-tests were used to assess generalizability.

Limitations

Limitations of this study lie in part in the validity and reliability of the measures. Self-report data has the potential for inaccuracies. The effect of this limitation can be minimized by providing subjects with a clear description of all answer choices and a reminder that reporting valid information is essential to the outcome of the study.

The WOMBAT-CS is one of very few quantitative measures of situation awareness. It has, however, been demonstrated to be a valid measure of situation awareness and pilot selection in the aviation industry. No studies have attempted to use it or validate it in the medical domain. Validity of the WOMBAT-CS in the population of GSRNAs has been assumed in this study after a thorough comparison of anesthesia and aviation has revealed many similar environmental characteristics.

Limitations surround the use of multiple regression analysis. At best, regression analysis may reveal associations among variables but do not infer causal relationships. A strong association between variables may be due to influences of other unmeasured variables (Tabachnick & Fidel, 2007). A regression solution is extremely susceptible to the combination of variables that it includes and assumes that the variables have been measured without error; this is rarely the case. Also, when employing regression analysis, the model assumes that requirements pertaining to homoscedasticity, linearity, normality, and multicollinearity have been met (Tabachnick & Fidel, 2007). Every attempt was made in the study to satisfy these assumption requirements.

The convenience sample of nurse anesthesia programs from Virginia Commonwealth University, Samford University, and Louisiana State University is subject to bias and may misrepresent other nurse anesthesia programs from around the US. The use of convenience sampling is a consideration when generalizing results of this study to the entire population of GSRNAs. Also, this proposed study depended on the voluntary cooperation of participants. The pitfall with using volunteers is the likelihood that they differ from non-volunteers, further compromising the interpretation and generalizability of the results (Isaac & Michael, 1997).

Human Subjects

Submission for expedited review was made to the Institutional Review Boards (IRB) at Virginia Commonwealth University. This fulfilled requirements mandated by the IRBs at Samford Univeristy and Louisiana State University Expedited review was awarded and is appropriate for research that examines such individual characteristics as perception, cognition, motivation, identity, language, communication, cultural beliefs or practices, or social behavior and presents no more than minimal risk to human subjects (Virginia Commonwealth University, 2008). Since a record of subject names and assigned research numbers was maintained and a face-to-face oral exam was given, information obtained from subjects has the potential to be identified; therefore exempt status was not sought.

Chapter Summary

This chapter discussed the methods by which a non-experimental, correlational design was used to develop a best evidence predictor model of situation awareness in Graduate Student Registered Nurse Anesthetists. A detailed description of the study plan to examine a) the extent to which memory, cognition, and automaticity are related to situation awareness, b) the extent to which any relationship amongst memory, cognition, and automaticity mediates their relationship with situation awareness, and c) the extent to which Endsley's theory of situation awareness is supported in the GSRNA population was provided. Information regarding population, recruitment, sampling methods, variables, data collection, hypotheses, and statistical analysis as well as limitations of the study was described. The approach to multi-site IRB approval was also discussed.

CHAPTER FOUR: RESULTS

Situation awareness (SA) has been identified as a key construct in the effective management of complex systems such as aviation, the military, and medicine. The purpose of this research was to explore situation awareness in nurse anesthesia and to provide nurse anesthesia educators with a best evidence predictor model of situation awareness in the GSRNA population for curricular enhancement. In this study, situation awareness was investigated at the individual level by exploring the relationships between memory, cognition, and automaticity, age, and gender and SA.

A descriptive, non-experimental, cross-sectional, correlational design was used to meet three study objectives: a) to determine the extent to which memory, cognition, and automaticity are related to situation awareness, b) to determine the extent to which any relationship amongst memory, cognition, and automaticity mediates their relationship with situation awareness, and c) to determine the extent to which Endsley's theory of situation awareness is validated in the GSRNA population.

Chapter Four describes the data preparation process and the quantitative results of the statistical analyses addressing the relationship between and among variables. The chapter begins with a discussion of the observed variables followed by an explanation of the data cleaning and preparation process. The statistical results as they relate to the research objectives and hypotheses are then summarized. Table 7 defines the relevant variable abbreviations used throughout the multiple regression analysis.

Table 7.

Description of Variable Abbreviations

GENDER	Gender	Covariate
AGE	Age in Years	Covariate
AGELG	Transformed Age in Yrs	Natural Log of AGE
MEMR	Memory	Predictor
MEMRZ	Transformed Memory	Z-Transformation of MEMR
COGN	Cognition	Predictor
AUTO	Automaticity	Predictor
AUTOZ	Transformed Automaticity	Z-Transformation of AUTO
SA	Situation Awareness	Criterion

Data

Review of Data Collection

After IRB approval from VCU, data was collected from a random sample of GSRNAs enrolled in the nurse anesthesia programs at Virginia Commonwealth University (VCU), Samford University (SU), and Louisiana State University (LSU). The data collection phase lasted for four weeks at each geographic location except for SU where data was collected over only a three week period. The data collection phase was shortened at SU to take advantage of a small window of opportunity to commence data collection at LSU. Data was collected on a total of 111 subjects (n=111).

Data Preparation and Cleaning

Data collected on all measures were manually entered into an Excel spreadsheet by the primary researcher. Data were proofread and inspected for accuracy. Value labels were assigned to gender (M=0, F=1) and data were imported into the Statistical Package for the Social Sciences (SPSS) 17.0 for analysis. Interestingly, 35% of cases (n=39) were drawn from VCU, 34% (n=38) from SU, and 31% (n=34) from LSU. As planned, the number of cases within groups is reasonably balanced (Figure 5).

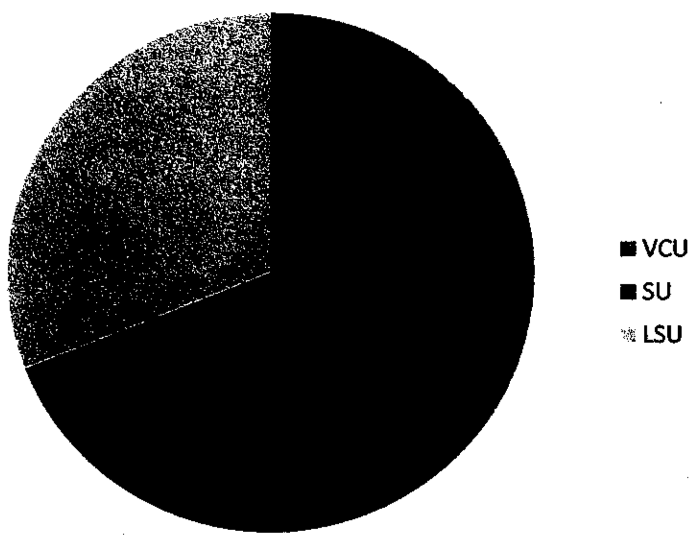

Figure 5: Distribution of cases by geographic location

All variables were initially assessed for distribution, assumptions, and outliers through descriptive statistics, frequency histograms, normal p-plots, and detrended normal p-plots. Data collected on all variables were screened for normality by examining skewness and kurtosis. Remarkable findings are discussed in this section.

Although Endsley's theory of situation awareness does not incorporate gender, the inclusion of gender in this study establishes a deeper understanding of what contributes to situation awareness in GSRNAs. On initial inspection of the raw data for gender (GENDER), cases identified as female (n=79) comprised 71% of the sample and cases identified as male (n=32) comprised 29% of the sample (Figure 6).

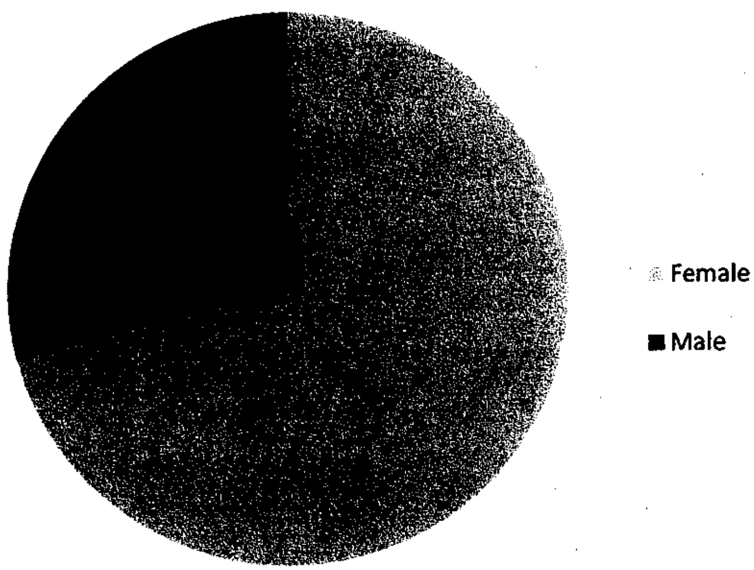

Figure 6: Distribution of cases by gender

The covariate age (AGE) was included in the study for reasons similar to that of gender in that it establishes a deeper understanding of how age may or may not contribute to situation awareness in GSRNAs. Endsley's (2000) theory does not consider age, but suggests more research examining the affect of age on the acquisition of SA.

Data were present on age for all 111 cases in the sample. The covariate age (AGE) was measured in years and was positively skewed (z-score = 4.80) but had generalizable kurtosis (z-score =1.95). Given that 93% (n=103) of values fall below 39 years, skewness was handled by transforming the raw data into the natural log of AGE (AGELG) as suggested by Tabachnick & Fidell (2007).

The predictor, memory (MEMR), was measured by scores on the Digit Span examination (Wechsler, 1997). Higher scores on Digit Span mean more memory where lower scores on Digit Span mean less memory. Upon evaluation of descriptive statistics and visual inspection of histograms and p-plots, a data entry error was noted as a value for memory was entered incorrectly as 90 thereby contributing to the extreme skewness. The erred entry was subsequently corrected to reflect the true score of 9, but the distribution remained skewed and kurtotic. Therefore, the variable memory underwent z-transformation and labeled (MEMRZ). There were no missing values in this sample (n=111).

The predictor cognition (COGN) was measured by scores on the Raven's Standard Progressive Matrices (SPM) examination (Raven, 2003). Higher scores on the Raven's SPM means more cognition and eductive ability and lower scores on the Raven's SPM mean less cognition and eductive ability. Initial statistics on cognition revealed a relatively homogenous sample. Analysis revealed negative skewness (z-score = -3.75) and a standard z-score of kurtosis of 0.562; less than one standard deviation of normal. Transformations for skewness were considered after the final sample size was determined, but found to be unnecessary and were not performed. There were no missing values in this sample (N=111).

The length of time (in months) the subject worked as a Registered Nurse in an intensive care unit (ICU) before beginning the graduate nurse anesthesia program was used to measure the variable automaticity (AUTO). The greater the number of months spent working in the ICU as a registered nurse represents higher automaticity. Automaticity was initially positively skewed and kurtotic with standard scores of 6.29 and 4.87 respectively. The variable automaticity underwent z-transformation (AUTOZ) for skewness and kurtosis.

Situation awareness (SA) was measured by scores on the computer-based WOMBAT-CS examination. Higher scores on the WOMBAT-CS mean more SA and lower scores on the WOMBAT-CS mean less SA. Univariate outliers were identified for this variable on initial visual inspection of the data plot. However, skewness was transformed to a standard z-score of 0.42 and determined to lie within one standard deviation of normal. With 3.3 representing 95% confidence that the skew generalizes to normal, the WOMBAT-CS scores in the sample were generalizable to a normal distribution in the population of Graduate Student Registered Nurse Anesthetists (GSRNAs). Kurtosis was transformed to a standard score of -1.34 and, likewise, accepted as generalizable. Table 8 describes the normality statistics on the initial analysis of all variables.

Table 8.

Normality Statistics on Initial Analysis of Data

Variable	Z-Skewness	Z-Kurtosis	N
GENDER	4.14	-2.46	111
AGE	4.80	1.96	111
MEMR	39.68	199.30	111
COGN	-3.75	0.56	111
AUTO	6.30	4.88	111
SA	0.42	-1.35	75*

*Denotes number of values left due to missing data.

A Missing Values Analysis (MVA) (SPSS 17.0) identified the extent to which 36 missing scores on the WOMBAT-CS affected the analysis. Little's MCAR test revealed that missing values were not missing completely at random (NMAR) ($\chi^2 = 26.26$, df =8, p=.001). As a result, all cases missing WOMBAT-CS scores were eliminated from the analysis leaving 75 valid cases. A power analysis indicated that a minimum sample size of 57 was required to achieve type II power of at least .8 (Green, 1991; Soper, 2009).

The existence of multivariate outliers was assessed using Mahalanobis distance statistics resulting from a regression analysis of residuals. The procedure is based on the fact that residuals will distribute normally and as a result, residual scores at the extremes of a distribution can be eliminated if there is a logical reason to do so (Tabachnick &

Fidell, 2007). In this study, ten cases were identified as multivariate outliers. Four of the ten cases were eliminated from the final analysis based on the researcher's review of the raw data and subsequent identification of suspect scores: two scores on Digit Span and two scores on WOMBAT-CS. Additionally, predicted scores for these four cases using all available data were 12.8 or more standard deviations from the predicted value of the residual. Removal of all cases with missing scores on the WOMBAT-CS (n=36) and another four cases identified as multivariate outliers left a computable sample of n=71 and statistical power of .9 (Figure 7). Statistical power of this strength is adequate to minimize Type II error (Tabachnick & Fidell, 2007).

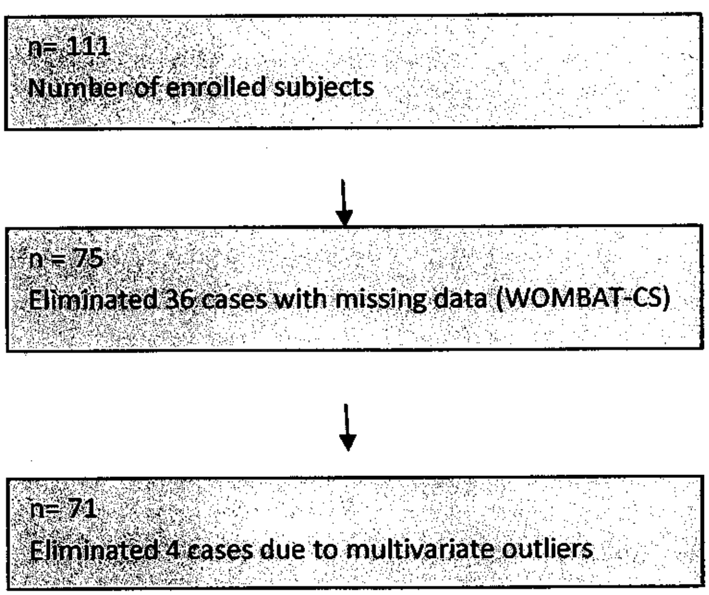

Figure 7. Impact of data cleaning and preparation process on case number (n)

Data Analysis

The section describes each observed variable in the final analysis and presents the overall results of the analyses of 71 cases which provided evidence relevant to the research hypotheses ($H_1 - H_4$). The first three hypotheses, H_1 through H_3, address the relationship between memory (MEMR) and SA, cognition (COGN) and SA, and automaticity (AUTO) and SA, respectively. Simple correlations and their significance provide the statistical evidence for these hypotheses (Myles & Gin, 2000). The final hypothesis, H_4, addresses the relationship between the combination of memory (MEMR), cognition (COGN), and automaticity (AUTO), and SA. Two-step multiple linear regression provides effect size and inference statistics relevant to Hypothesis Four (H_4).

Descriptive Statistics

Descriptive statistics on each observed variable are presented in Table 9 and include number of cases (n), mean, standard deviation (SD), variance, standardized skewness, standardized kurtosis, and minimum and maximum values.

After data cleaning, 49% (n=35) of cases came from VCU, 28% (n=20) from SU, and 23% (n=16) from LSU (Figure 8). This is not surprising since the researcher was on-site at VCU but not at SU and LSU during WOMBAT-CS testing and VCU subjects may have felt more compelled to complete this portion of the study due to the continuous presence of the researcher.

Table 9.

Descriptive Statistics of Observed Variables before Transformations, n=71

	GENDER	AGE	MEMR	COGN	AUTO	SA
Mean	0.690	30.859	9.718	54.479	51.887	150.155
SD	0.465	4.608	2.468	3.388	36.628	73.866
Variance	0.216	21.237	6.091	11.482	1341.644	5456.213
Z of Skew		3.594	3.502	-2.548	4.882	0.289
Z of Kurt		2.081	4.291	0.884	3.982	-1.138
Minimum	0	25	5	44	10	11.7
Maximum	1	46	19	60	192	333.8

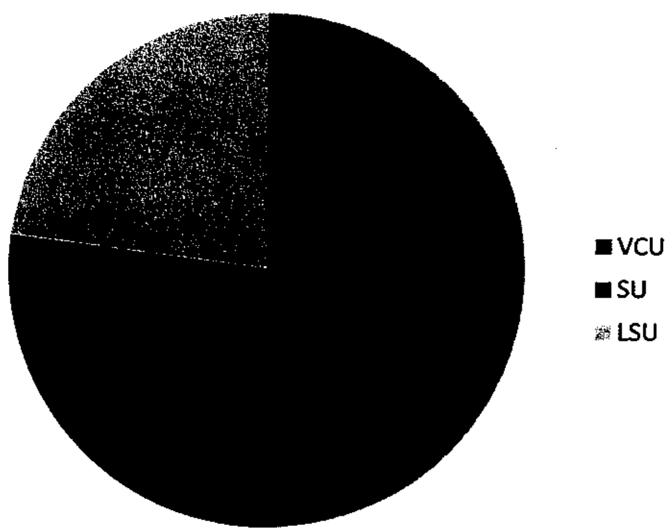

Figure 8: Distribution of cases by geographic location after data cleaning

GENDER represents the single categorical variable. Females comprise 69% (n=49) of the sample where males comprise 31% (n=22) of the sample. (Figure 9). This pattern of distribution is not congruent with the distribution of males and females in the population of Certified Registered Nurse Anesthetists (CRNAs) in the US. Current results of a demographic survey of CRNAs by the American Association of Nurse Anesthetists revealed a distribution of 50% males and 50% females (AANA, 2009).

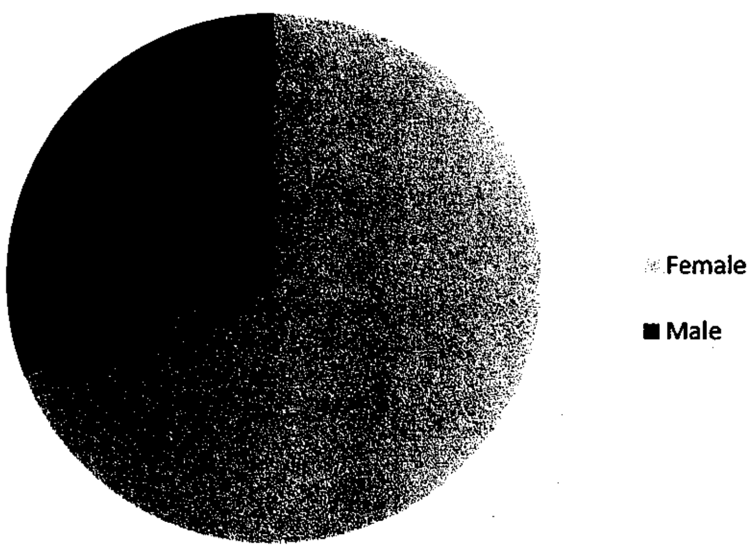

Figure 9: Distribution of cases by gender after data cleaning

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To address this discrepancy, a one-way homogeneity of variance test for gender against each predictor and the criterion SA, was performed to determine if significant variance between females and males on each variable existed (Green, 1991). Levene's statistic was used to test the null hypothesis that the variances of the group are the same.

Levene's statistic revealed no significant violation of homogeneity of variance for any of the study variables (Table 10) indicating equal variance for males and females on all of the observed variables. Therefore, no transformations were made to the variable gender. There were no missing values in the sample (n=71).

Table 10.

Test of Homogeneity of Variances (GENDER)

	Levene Statistic	dfl	df2	Sig.
AGE	.077	1	69	.782
MEMR	.278	1	69	.600
COGN	.381	1	69	.539
AUTO	2.575	1	69	.113
SA	.519	1	69	.474

Age (measured in years) served as a covariate in the analysis to explore its relationship with SA in the population of GSRNAs. The sample mean was 30.9 years with an 1). SD of 4.61. The sample ranged from 25 to 46 years at the time of testing. On standardized scores, age was positively skewed (3.6) but had generalizable kurtosis (2.1) (Figure 10).

Skew was corrected with a transformation of age to the natural log of age and labeled AGELG. The transformation reduced the original positive standardized skew

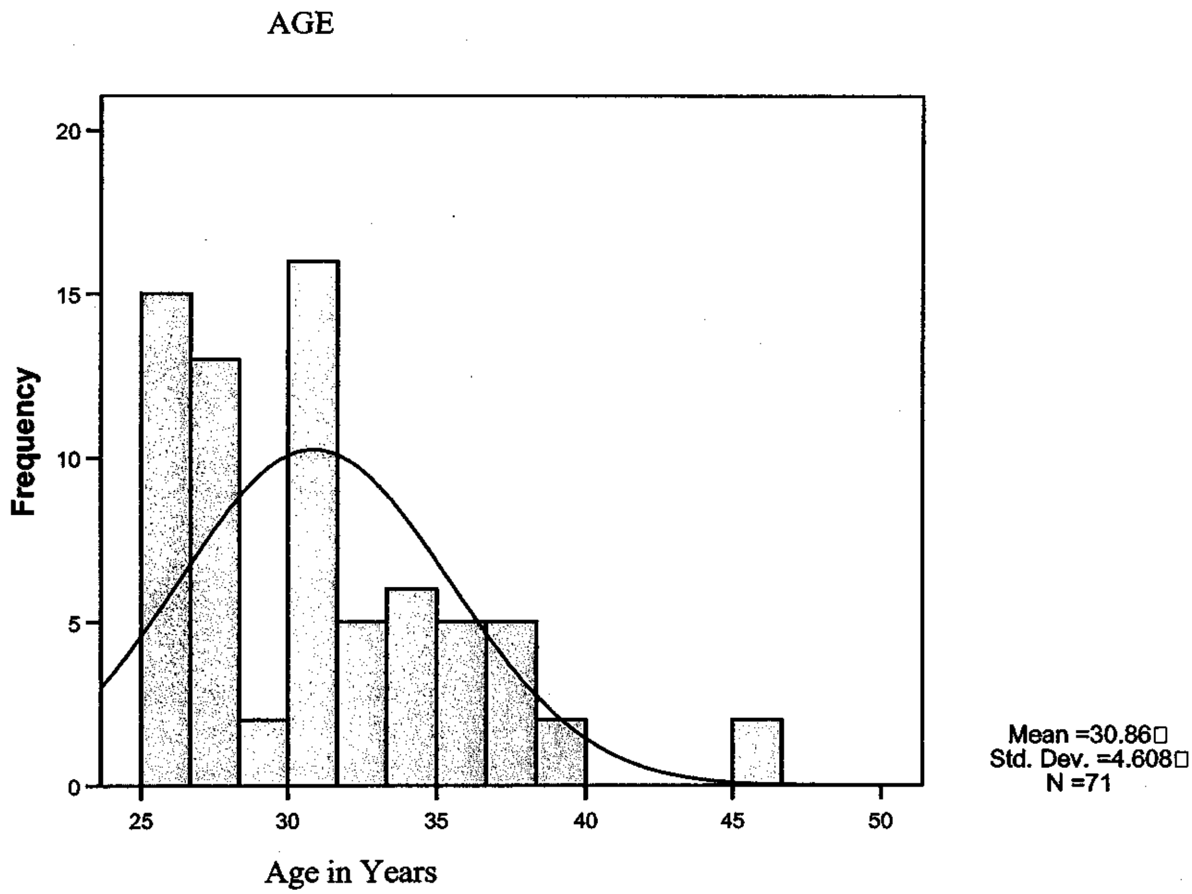

Figure 10: Frequency histogram revealing positive skew of AGE before natural log transformation.

All graphs produced in SPSS 17.0, 2008.

from 4.8 to 2.3, an acceptable range to generalize to a normal population of GSRNAs (Table 11). The transformation did not affect the linear relationships among the study variables. Age was related to its transform (AGELG) with *r*=.996. This evidence

Table 11.

Descriptive statistics for AGELG.

AGELG

N	Valid	71
	Missing	0
Mean		1.4849
Std. Deviation		.06182
Variance		.004
Z Skewness		2.287
Z Kurtosis		.073
Minimum		1.40
Maximum		1.66

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suggested that the transformed value (AGELG), meeting the assumption of normality, was appropriate to enter into the final analysis.

Memory was measured by scores on Digit Span (Wechsler, 1997). The mean value for memory was 9.7 digits with an SD of 2.45. Scores ranged from a low of 5 to a high of 19 digits (Figure 11). Current literature reflects a normal memory capacity to range from 7 to 10 items (Baddeley, 1996). The standardized score on skewness for

MEMORY

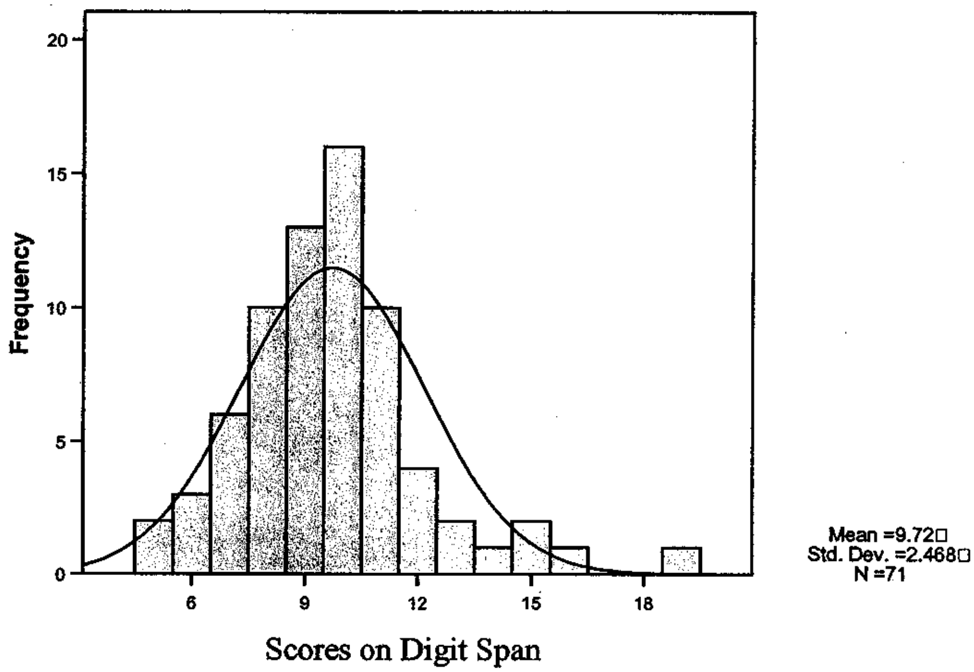

Figure 11: Frequency histogram of scores on Digit Span before z-transformation.

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memory in this sample was 3.5. Similarly, the standardized score on kurtosis for memory in this sample was 4.3. Analysis reveals that 74% of cases (n=53) had scores between 8 and 12 digits.

Because the range suggested univariate outliers but the data were normally distributed, generalizability was possible, however it is limited to scores in the middle of the distribution. Therefore, a z-transformation was performed on memory and labeled MEMRZ (Table 12). The transformation did not affect the linear relationship among

Table 12.

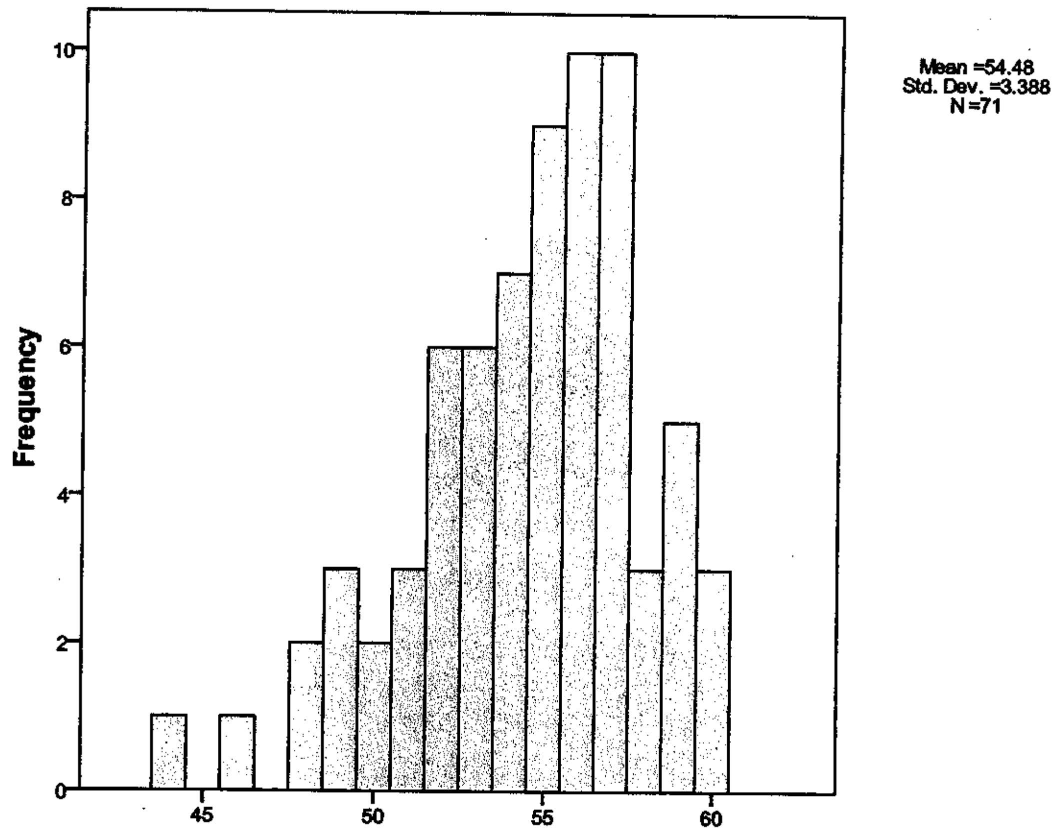
Descriptive Statistics on MEMRZ and AUTOZ

	N	Minimum	Maximum	Mean	Std. Deviation
MEMR	71	5	19	9.72	2.468
MEMRZ	71	-1.91181	3.76084	.00000000	1.00000000
AUTO	71	10	192	51.89	36.628
AUTOZ	71	-1.14357	3.82524	.000000	1.00000000

observed variables. Memory was related to its transform (MEMRZ) with r= 1.0. This evidence suggested that the transformed variable for memory (MEMRZ), meeting the assumption of normality, was appropriate to enter into the final analysis. The transformation affected Type I error in the extremes. There were no missing values in the sample.

Cognition was measured by scores on the Raven's Standard Progressive Matrices (SPM) examination. The mean value for cognition was 54.5 with an SD of 3.39. Scores ranged from a low of 44 to a high of 60 (Figure 12). Sixty was the highest score possible. This represented a relatively homogenous sample. After the final sample size was determined (n=71), the standard score of skewness was -2.54 (less than 3.3) which supported generalizability to the population of GSRNAs with 95% confidence. The standardized score for kurtosis was .884; less than a standard deviation of normal.

COGNITION



Raw Scores on Raven's SPM

Figure 12: Frequency histogram of raw scores on Raven's SPM.

Cognition was sufficiently normally distributed and appropriate to use in this study. There were no apparent univariate outliers and no missing values in the sample.

Automaticity was measured by the length of time (in months) subjects worked as Registered Nurses in the ICU before admission into the nurse anesthesia program. The mean value for AUTO was 51.9 months with an SD of 36.63. Scores ranged from a low of 12 to a high of 192 months. Figure 13 reveals considerable skewness (z-score 4.88) and kurtosis (z-score 3.98) on automaticity after data cleaning.

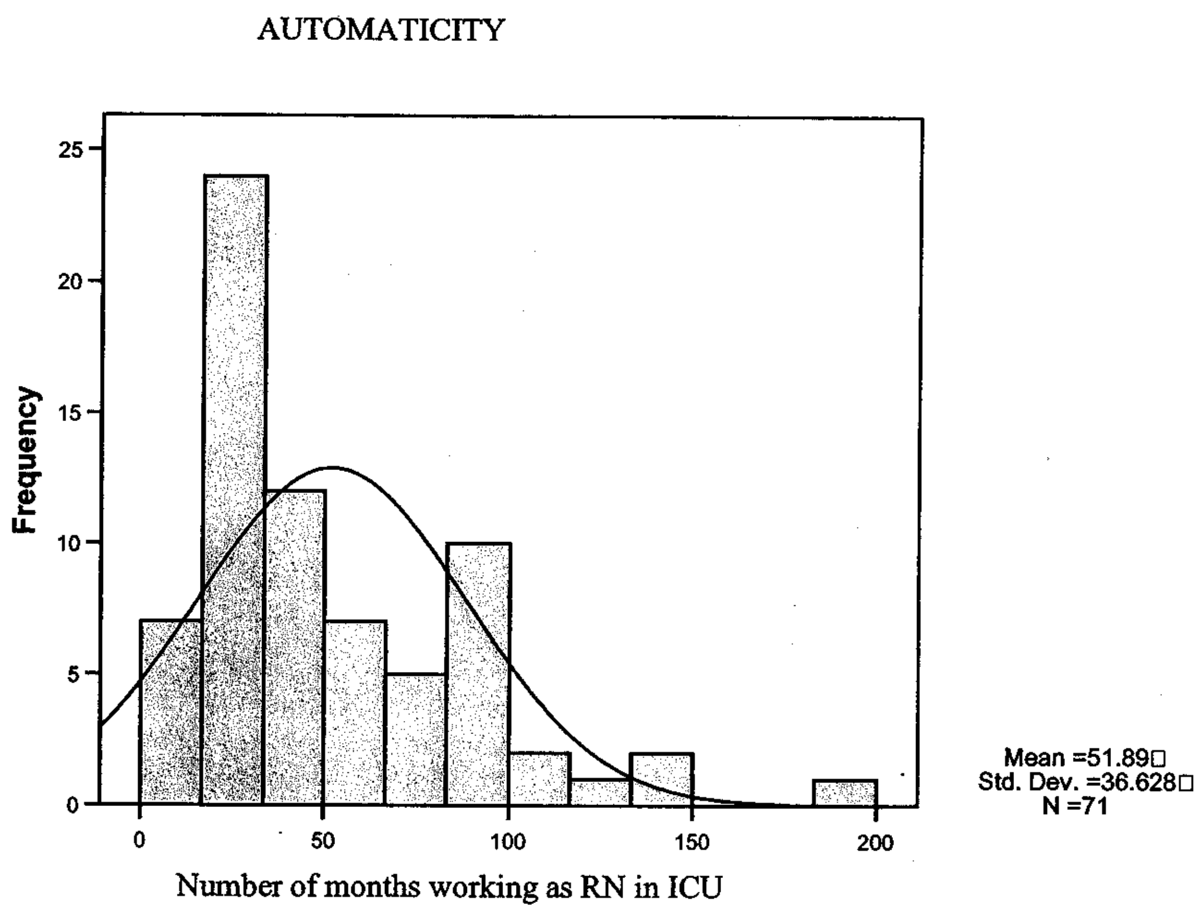


Figure 13: Frequency histogram of AUTO before z-transformation.

A large number of cases had relatively little ICU experience while a few appeared as outliers with a large number of months of experience. Given the pattern of the data, a z-transformation on automaticity was performed to account for the distribution of data expected in a population of GSRNAs thereby creating a variable AUTOZ (Table 12).

transformation did not affect the linear relationship among observed variables. Automaticity was related to its transform (AUTOZ) with r= 1.0. This evidence suggested that the transformed variable for automaticity (AUTOZ), meeting the assumption of normality, was appropriate to enter into the final analysis. There were no missing values in the sample (n=71).

Situation Awareness. Situation awareness (SA) was measured by quantitative scores on the WOMBAT-CS computer-based examination of situation awareness. The mean value for SA was 150.2 with an SD of 73.87. Scores ranged from 11.7 to 333.8. Skewness, transformed to a standardized score of .289, was within one standard deviation of normal. Kurtosis, transformed to a standardized score of -1.13, was between one and two standard deviations of normal. With 3.3 representing 95% confidence that the skew generalized to normal, the WOMBAT-CS score in the sample was generalizable to a normal distribution in the population of GSRNAs (Figure 14). There were no missing values in the final sample (n=71).

Hypothesis Testing

After correcting for univariate and multivariate outliers, reviewing the descriptive data analysis, and confirming that variables were not in violation of the assumptions of normality, linearity, and homoscedasticity, the four research hypotheses were tested.

Hypotheses One (H_1)

Hypothesis One (H_1) posited that GSRNAs with higher levels of memory will also demonstrate higher levels of situation awareness:

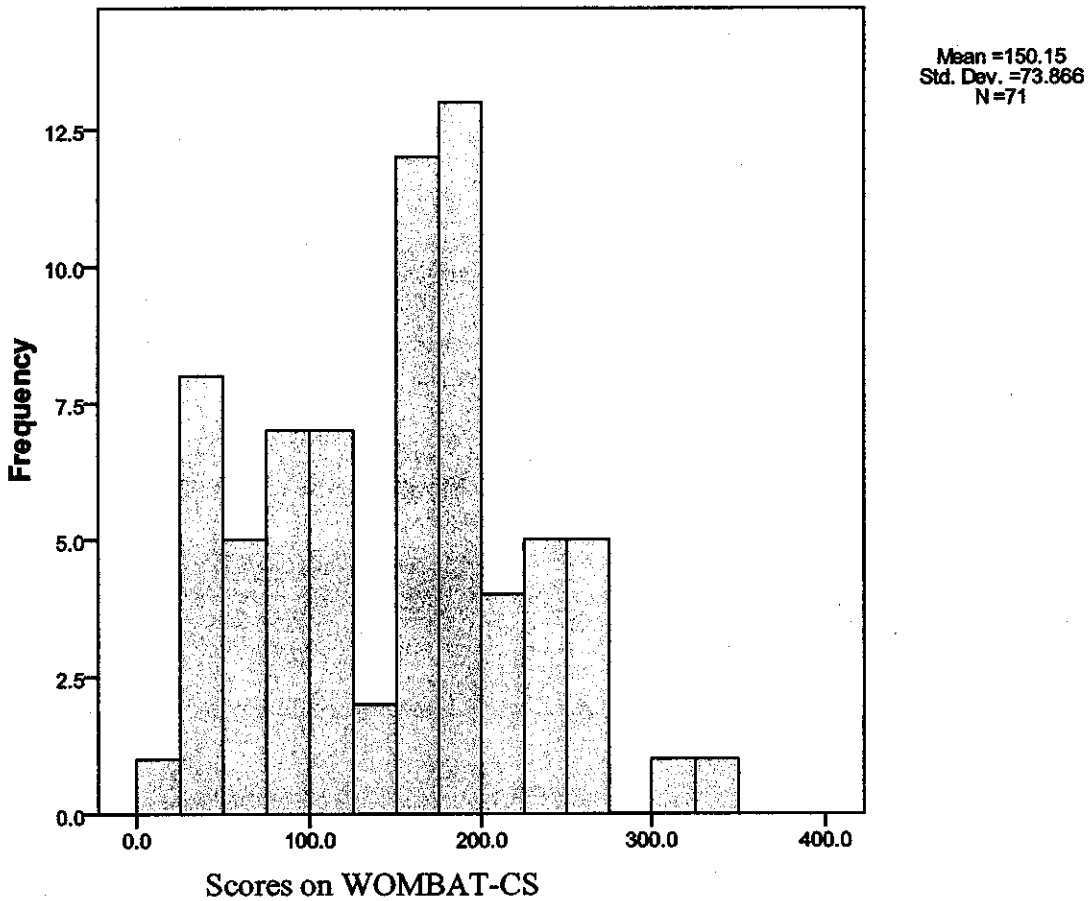


Figure 14: Frequency histogram of scores on WOMBAT-CS.

Hypothesis one (H_1): **There will be a direct positive linear relationship between memory and situation awareness in the GSRNA population.**

Hypothesis One was tested by computing a Pearson Product Moment Correlation (r) on the variables memory and SA. Correlation matrix output from SPSS 17.0 revealed an r value of 0.204 (p =0.088) indicating a mild association between memory and situation awareness (Table 13) (Myles & Gin, 2000). This evidence provides minimal support of Hypothesis One (H_1). The coefficient of determination (r^2) between memory and SA is computed as 0.042 indicating that 4.2% of the variance in SA is explained by the variance in memory.

Table 13.

Correlation Matrix of Predictor and Criterion Variables.

		AGELG	MEMRZ	COGN	AUTOZ	SA
AGELG	r	1	-.141	-.001	.622(**)	-.191
	Sig. (2-tailed)		.239	.990	.000	.111
MEMRZ	r		1	.112	-.244(*)	.204
	Sig. (2-tailed)			.352	.041	.088
COGN	r			1	-.073	.442(**)
	Sig. (2-tailed)				.548	.000
AUTOZ	r				1	-.128
	Sig. (2-tailed)					.287
SA	r					1
	Sig. (2-tailed)					

** Correlation is significant at the 0.01 level.

* Correlation is significant at the 0.05 level.

Hypothesis Two (H_2)

Hypothesis Two posited that GSRNAs with higher levels of cognition will also demonstrate higher levels of situation awareness:

> *Hypothesis one (H_2):* **There will be a direct positive linear relationship between cognition and situation awareness in the GSRNA population.**

Hypothesis Two was tested by computing a Pearson Product Moment Correlation (r) on the variables COGN and SA. Correlation matrix output from SPSS 17.0 revealed a moderate association between cognition and SA with an r value of 0.442 ($p = 0.000$) (Table 13) which is statistically significant at the .01 level (two-tailed) and provides sufficient evidence to support Hypothesis Two (H_2). The coefficient of determination (r^2) between cognition and SA was calculated as 0.195 indicating that around 20% of the variance in SA is explained by the variance in cognition.

Hypothesis Three (H_3)

Hypothesis Three suggested that GSRNAs with higher levels of automaticity will also demonstrate higher levels of situation awareness:

> *Hypothesis one (H_3):* **There will be a direct positive linear relationship between automaticity and situation awareness in the GSRNA population.**

Hypothesis Three was tested by computing a Pearson Product Moment Correlation (r) on the variables automaticity and SA. Correlation matrix output from SPSS 17.0 revealed an r value of -0.128 ($p = 0.287$) (Table 13) which does not provide adequate evidence to support Hypothesis Three (H_3). The coefficient of determination (r^2) between automaticity and SA was computed as 0.016 indicating that 1.6% of the variance in SA is explained by the variance in AUTOZ.

The correlation matrix revealed two significant relationships between variables other than those hypothesized in this study. A relationship between memory and automaticity was discovered in the analysis. The Pearson correlation (r) on variables memory and automaticity was calculated as -0.244 ($p = .041$) (Table 14). This suggested an inverse relationship between memory and automaticity: as years working in the ICU increase, memory decreases. An explanation of this relationship may lie in the fact that older nurses are more likely to have worked in the ICU longer than younger nurses and memory declines with age.

Similarly, but not surprisingly, the Pearson correlation (*r*) on variables age and automaticity was computed as 0.622 (p =0.000) (Table 13). A Pearson's *r* of this magnitude suggests a relationship between age and automaticity that is unlikely to be explained by chance alone. This finding supports the idea that the older the subject, the More time he or she has spent in the ICU working as an RN. One would not expect a younger subject to work in the ICU before entering a nurse anesthesia program for as long a period of time as an older subject.

Hypothesis Four (H_4)

Statistical (stepwise) regression was employed to test Hypothesis Four (H_4). Hypothesis Four suggested that all three predictors (memory, cognition, and automaticity) would together provide a more predictive model of situation awareness in GSRNAs than any individual predictor alone.

> *Hypothesis four (H_4):* **A combination of memory, cognition, and automaticity will produce a more predictive model of situation awareness in the GSRNA population than that produced by memory, cognition, or automaticity alone.**

As a preliminary analysis, both covariates (gender and age) and all predictors (memory, cognition, and automaticity) were entered against the criterion (SA). A single variable, cognition, was determined to be significant (F=16.87, df= 1/69, p <0 .001) to enter into the final regression analysis. Cognition and SA had both a univariate and multivariate *r* value of 0.442, explaining nearly 20% of the variance in SA (Table 14).

Table 14.

Model Summary of the Regression Analysis - Part A

					Change Statistics				
Model	R	R Square	Adjusted R Square	Std Error of the Estimate	R Square Change	F Change	df1	df2	Sig. F Change
1	.442 (a)	.196	.184	66.7262	.196	16.782	1	69	.000

a Predictors: (Constant), COGN

Age and memory were half as important as cognition and of approximately equal importance when compared to each other, with partial correlations of -0.21 and 0.17 respectively. Age approached significance (t = -0.17, p=0.077) (Table 15). An identical analysis was performed with gender and age as covariates and memory, cognition, and automaticity as predictors. The same model resulted. With only one predictor contributing to the model, squared semi-partial correlations (sr_i^2) to determine the unique contribution of each predictor were not computed.

Based on the stepwise regression, there was not enough evidence to support Hypothesis Four (H_4). It appears that cognition best predicts SA in the population of Graduate Student Registered Nurse Anesthetists, with the addition of memory and automaticity contributing no additional predictive value to the model.

Chapter Summary

This chapter presented the statistical analysis and results of this study which aims to describe a best evidence predictor model of situation awareness in Graduate Student Registered Nurse Anesthetists. The relationships between and among memory, cognition, and automaticity and situation awareness were quantified and analyzed using stepwise linear regression including beta weights, partial correlations, and correlation matrices. The findings revealed support for cognition as the best predictor of situation awareness in Graduate Student Registered Nurse Anesthetists. No evidence that gender, age, memory or automaticity predict situation awareness in this population was discovered. Chapter Five will discuss the research findings in light of the study objectives, present the limitations of the study, and offer recommendations for future research.

Table 15.

Model Summary of the Regression Analysis - Part B

ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	74719.839	1	74719.839	16.782	.000(a)
	Residual	307215.057	69	4452.392		
	Total	381934.896	70			

a Predictors: (Constant), COGN
b Dependent Variable: SA

Coefficients

Model		Unstandardized Coefficients		Standardized Coefficients			95% Confidence Interval for B	
		B	Std. Error	Beta	t	Sig.	Lower Bound	Upper Bound
1	(Constant)	-375.129	128.469		-2.920	.005	-631.418	-118.840
	COGN	9.642	2.354	.442	4.097	.000	4.947	14.337

a Dependent Variable: SA

Excluded Variables(b)

Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics
						Tolerance
1	GENDER	.012(a)	.113	.910	.014	.997
	AGELG	-.191(a)	-1.794	.077	-.213	1.000
	AUTOZ	-.097(a)	-.891	.376	-.107	.995
	MEMRZ	.156(a)	1.449	.152	.173	.987

a Predictors in the Model: (Constant), COGN
b Dependent Variable: SA

CHAPTER FIVE: DISCUSSION

Chapter Five presents a synopsis of the study and an interpretation of the results as described in Chapter Four. The findings of the study are reviewed in the context of the research hypotheses and both theoretical and practical implications are discussed. Finally, limitations of the study are examined and recommendations for future research are conveyed.

Summary and Overview of the Problem

Since the 1980's, the patient safety movement has generated many promising efforts in improving quality and reducing error, but the very complex and dynamic nature of the health care industry demands continuous study and further empirical research. The specialty of anesthesiology, along with emergency medicine and obstetrics, has been identified as areas highly vulnerable to error. The environment in and processes by which anesthesia services are delivered are complicated and risky as evidenced by a steady stream of malpractice claims made against anesthesia providers as well as continued patient injury and death (Aitkenhead, 2005; Caplan, 2000; Cheney, 1999; Gaba, Fish & Howard, 1994).

Human factors have been implicated as major contributors to error in anesthesia. Situation awareness is one such human factor which describes an operator's ability to perceive the elements of the environment, comprehend their meaning, and project their status in the future (Endsley & Garland, 2000). Effective crisis management skills include non-technical skills such as the acquisition of situation awareness. Research focused on the enhancement of non-technical skills, including situation awareness, has only recently become an area of interest in the specialty of anesthesia (Gaba et al., 1998, Fletcher et al., 2002, Fletcher, et al., 2003, Weller et al., 2003, Yee et al, 2005). Given the importance of situation awareness in the provision of safe anesthesia care, an understanding of how anesthesia providers acquire SA is relevant and fertile ground for study.

Nurse anesthesia educational programs in the United States are charged with preparing graduates to successfully meet the challenges of providing safe and effective anesthesia care. Standard curricula include didactic teaching of the foundational principles of physiology, pharmacology, chemistry and anesthesiology. Additionally, GSRNAs gain clinical knowledge through clinical preceptorships in various anesthetizing locations that include hospital operating rooms. Due to the infrequent occurrence of anesthesia accidents, rarely do didactic instruction in the classroom and clinical preceptorships provide GSRNAs with adequate experience in managing anesthesia-related crises, when indeed these are among the most critical times that define their role.

Purpose of the Study

The purpose of this study was to explore SA in nurse anesthesia and to provide nurse anesthesia educators with a best evidence predictor model of situation awareness in the GSRNA population for curricular enhancement. This study examined situation awareness at the individual level by exploring relationships between memory, cognition, and automaticity and situation awareness in this group.

Review of Theory and Research Question

Reason (1990) and Rasmussen (2003) provide two well-accepted theories of human error. Reason describes error as a result of active failures, or triggers, coming into contact with latent factors, such as inadequate situation awareness, which are like fault lines and lie dormant within a system. Rasmussen (2003) discusses error as a product of human adaptation to the work environment. He posits that performance in dynamic and complex work conditions requires continuous and adequate awareness of the environment as tentative decisions are considered for effective problem-solving. Both Reason (1990) and Rasmussen (2003) suggest situation awareness as a requisite skill to reduce the incidence of error.

Situation awareness is vital for processing information (Endsley & Garland, 2000). Information processing theory proposes that information is processed and stored in stages with a heavy emphasis on memory (Atkinson & Shiffrin, 1968). Similarly, attention is a key factor dictating what information moves from short-term memory to long-term memory. Consequently, long-term memory has a profound influence on attention allocation and perception.

Endsley's (2000) theory of situation awareness was derived from information processing theory and describes how operators of complex systems select, process, and interpret information. Situation awareness is defined as "one's perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future". Endsley (2000) has long suggested that in addition to contextual elements, personal attributes, such as memory, cognition, and automaticity, influence one's ability to acquire and maintain situation awareness.

This study was designed to explore situation awareness in nurse anesthesia graduate students and to investigate the relationship between situation awareness and the personal attributes of memory, cognition, and automaticity. The research question posed was: Is there a relationship between situation awareness and memory, cognition, and automaticity in Graduate Student Registered Nurse Anesthetists?

Methodology

A non-experimental, correlational design was used to examine key constructs of situation awareness at the individual level in an effort to develop a best evidence predictor model of situation awareness in Graduate Student Registered Nurse Anesthetists. After human subjects consideration, data were gathered at three US universities to yield a sample final size of 71 subjects. Descriptive statistics were used to characterize the sample in order to examine the relationship between independent variables. Where a relationship was sought between each memory, cognition, and automaticity and situation awareness, a Pearson Product-Moment correlation coefficient was computed. To investigate which variable(s) comprise a best evidence predictor model of situation awareness in GSRNAs, a stepwise linear regression analysis was performed.

Study Findings

In this section, the findings of the study are reviewed in the context of the hypotheses and research objectives. Additionally, both theoretical and practical implications are presented in light of the literature review. Study results suggest that cognition best predicts situation awareness in Graduate Student Registered Nurse Anesthetists with no contribution to the predictor model made by memory or automaticity.

Hypotheses

Two of the four hypotheses proposed in the study were supported.

Hypothesis one (H_1): **There will be a direct positive linear relationship between memory and situation awareness in the GSRNA population.**

An examination of Pearson's correlation coefficient (r=.204, p=.088) reveals a mild positive relationship between memory and situation awareness in GSRNAs (Myles & Gin, 2000).

Hypothesis one (H_2): **There will be a direct positive linear relationship between cognition and situation awareness in the GSRNA population.**

An examination of Pearson's correlation coefficient (r=.442, p=.000) reveals a moderate and statistically significant positive relationship between cognition and situation awareness in GSRNAs (Myles & Gin, 2000). Significant relationships between cognition and other study variables were not discovered.

Hypothesis one (H_3): **There will be a direct positive linear relationship between automaticity and situation awareness in the GSRNA population.**

An examination of Pearson's correlation coefficient (r=-.128) reveals no significant association between automaticity and situation awareness. However, a significant positive correlation between automaticity and the covariate, age, was revealed (r=.622, p=.000).

Hypothesis one (H_4): **A combination of memory, cognition, and automaticity will produce a more predictive model of situation awareness in the GSRNA population than that produced by memory, cognition, or automaticity alone.**

The stepwise linear regression analysis revealed cognition as the sole predictor of situation awareness in GSRNAs. The inclusion of memory and automaticity to the regression analysis contributed no greater predictive value to the final model than cognition alone.

Application to the Literature

Although anecdotal evidence and intuition suggest individual differences in SA, only one study was discovered in the literature review which examined these differences among operators of complex systems. Bolstad and Endsley (1994) investigated fighter pilots' innate potential for developing SA. The researchers specifically tested the relationships between spatial ability, attention, memory, perception, cognitive function and locus of control and SA. While an association between spatial ability, perception, attention, and pattern matching were correlated with SA in this population of fighter pilots, the researchers uncovered no relationship between memory or cognition and SA. Similar to Bolstad and Endsley's (1993) study, this current research found only a very mild relationship (r=.204) between memory and SA in GSRNAs. Unlike the 1994 study, the current research found a significant positive relationship between cognitive ability and the development of SA in GSRNAs. The difference in instruments used to measure the criterion variable, SA, in the two studies may contribute to the variance in the findings. Bolstad and Endsley (1994) used the Situational Awareness Global Assessment Technique (SAGAT), a domain specific and subjective assessment of situation awareness, where the current research employed the WOMBAT-CS, a quantitative computer-based general assessment of SA.

The literature review on which this study was largely based identifies many similarities among operators of complex systems across domains. By the very nature of the complex operating room environments in which they work, nurse anesthetists are acknowledged as operators in complex systems. The findings of this study contribute to the current understanding of GSRNAs as operators of complex systems in a more empirical way. If it is speculated that operators of complex systems require high cognitive abilities to achieve SA, and this study reveals that GSRNAs with higher levels of cognition had higher SA scores, then a more powerful statement may now be made concerning the relationship between nurse anesthetists and operators of complex systems.

Implications

Theoretical Implications

Endsley's (2000) theory of situation awareness suggests that in addition to contextual factors, individual attributes play an essential role in the development of situation awareness. Such individual characteristics include operator goals and preconceptions, attention, memory, automaticity, pattern matching, and cognition. An assumption of this study is that GSRNAs share the same overarching goal of maximizing patient safety and minimizing morbidity and mortality by performing optimally. Similarly, it is assumed that GSRNAs, through pre-requisite shadowing experiences in the operating room, possess relatively commensurate preconceptions about the nature of the specialty of anesthesia.

While many individual characteristics are theorized by Endsley (2000) to predict situation awareness in operators of complex systems, this study in the GSRNA population specifically examines the relationships between memory, cognition, and automaticity and SA. These variables have the potential to be further explored and operationalized in curricular strategies in nurse anesthesia educational settings. Pattern matching was not included in this study because its ability to be developed and enhanced in a graduate nurse anesthesia curriculum is unknown. Results from this study confirm some aspects of Endsley's theory of SA. While a mild association (r=.204, p=.088) was found between memory and SA and no association was found between automaticity and SA in GSRNAs, a relationship between cognition and SA was found to be significant (r=.442, p=.000).

Since memory is associated with one's ability to process information, it is reasonable to suggest that SA is constrained by limits in memory capacity (Gugerty & Tirre, 2000). In the current study of GSRNAs, the variance in memory explained 4.2% of the variance in SA. It is possible that memory is not as important for the development of SA as posited by the theory. Memory, in a complex crisis situation, may be of less importance in fostering high levels of situation awareness than other individual attributes. Other plausible explanations for this finding may lie in the chosen measures of memory and SA, the motivation of subjects to perform well on the measures, and incongruent characteristics between GSRNAs and operators of complex systems. The contribution made by memory to the development of SA may be better understood if explored utilizing other valid and reliable measures and in the context of domain specific situations.

Cognition is a multi-dimensional construct that refers to the mechanism by which one processes information (Cannon-Bowers & Salas, 2006). In this study, cognition was measured by Raven's Standard Progressive Matrices (SPM) which is a valid and reliable measure of Spearman's *g* or eductive ability (Raven, 1989). Eductive ability is defined more specifically as one's capacity to make decisions and solve unfamiliar problems in complex situations by understanding relationships between various elements independent of language and previous knowledge (Raven, 1989).

Endsley (2000) theorizes that expert decision makers employ cognitive processes to instantly perceive information in their environment. Operators with superior cognitive abilities, in theory, have greater capacity to focus attention on continuous situational assessment leading to increased SA. The findings of the current study support a similar relationship; GSRNAs with higher cognitive abilities demonstrated greater situation awareness.

Automaticity is defined as performance that is highly routine and is theorized by Endsley (2000) to contribute to the development of SA by reducing attentional demands amidst intense physical and cognitive loads. Higher levels of automaticity should, according to Endsley (2000), reduce the time from environmental cue to appropriate response by the operator, thereby improving one's ability to acquire SA. Yet, the results of this study in the GSRNA population reveal a negative relationship between automaticity and SA. In contrast to Endsley's theory, a case may be made that automaticity and rote performance could potentially detract from one's ability to acquire all levels of SA in unfamiliar situations. As an operator expects the same response from a routine intervention time and time again, a different, unexpected response to that same intervention may challenge the operator's decision-making and problem-solving skills by misdirecting his or her attention from salient elements in the environment, thereby reducing SA. A less ambiguous definition of automaticity with more precise suggestions for measurement may provide a better understanding of its role in the theory and ultimately its role in developing SA.

Practical Implications

The results of this study have practical implications for nurse anesthesia educators and ultimately, for anesthesia providers and the countless patients for whom they provide care. Program directors and faculty of nurse anesthesia programs are challenged to teach students the essential theoretical and technical knowledge and skills necessary to be effective in the operating room environment and successful in passing the discipline specific National Certification Examination (NCE). Management of life threatening crises arising in the operating room is among the most challenging essentials to be taught and instilled in learners. Knowledge of what may or may not contribute to situation awareness in GSRNAs has the potential to assist educators in utilizing scarce human and capital resources efficiently and effectively to reach these programmatic outcomes.

In this study, memory was found to be mildly associated (r=.204) with SA in GSRNAs which, to a degree, lends some support to Endsley's theory that good memory is necessary for SA. Similarly, the association discovered between memory and SA supports information processing theory which claims that memory capacity determines how information is perceived, processed, stored, retrieved and forgotten. With this practical and theoretical knowledge, nurse anesthesia educators may choose to explore curricular strategies that enhance memory related to anesthesia-specific content and processes. One such curricular strategy involves the use of mnemonics to enhance immediate and delayed retention of information.

Mnemonic instruction is a teaching strategy designed to improve memory by allowing the learner to encode information in a manner that facilitates easy retrieval (Jaeggi, Buschkuehl, Jonides, & Perrig, 2008; Mastropieri & Scruggs, 2000). An example can be appreciated when considering the current challenge of nurse anesthesia educators in teaching the lengthy list of essential activities that needs to be completed in a timely manner after a patient's trachea is intubated, but before the surgical incision is made.. During this five to seven minute time period, the operating room environment is often rich with distractions and the anesthetist's attention can easily be misdirected.

The mnemonic, PATIENT, was recently developed by the researcher to address each critical checkpoint during this time and stands for **P**atient, position, **A**nesthesia, antibiotics, airway, **T**emperature, **I**V, **E**nd-tidal CO_2, **N**arcotics, and **T**witches. Teaching GSRNAs to remember and employ this mental checklist in a high-fidelity simulated operating room environment could potentially better prepare them to respond effectively and in a timely manner during this tumultuous time in the confines of the actual operating room. If a list of tasks can be practiced and mastered through the use of mnemonics, it is feasible that GSRNAs could then reserve higher-order cognitive processes for addressing newly-encountered anesthesia events and unfamiliar patient conditions, thereby enhancing SA.

Situation awareness most likely contributes to one's ability to solve problems effectively (Cannon-Bowles & Salas, 2000; Endsley & Garland, 2000; Gaba, Fish & Howard, 1995). Problem solving is regarded by many educational and cognitive psychologists as fundamental to learning (Halpern, 1998; Koh, Khoo, Wong & Kho, 2008; Wood, 2003; Cannon-Bowers & Salas, 2000). A learner is thought to analyze a problem by assigning it to some pre-existing mental model formed from previous experience. Cognitive processes allow the learner to reconcile the current problem with the pre-existing mental model in order to come to a solution. It is likely that learners of anesthesia, due to lack of experience, will not possess the reconciliation skills or mental models necessary for problem-solving in the operating room.

The use of simulated operating rooms in nurse anesthesia training programs shows promise for providing opportunities for GSRNAs to experience unfamiliar critical events. Through this exposure, students can potentially begin to create the mental models essential to effective problem-solving and accurate decision making under stressful conditions (Cannon-Bowers & Salas, 2000). Once mental models of these rare events exist, nurse anesthesia faculty can incorporate cognitive exercises, such as lateral thinking, mental manipulation of relationships, and reconciliation of information into hands-on training to promote SA.

Additionally, nurse anesthesia faculty may consider the feasibility of instructional methods which are grounded in anesthesia-specific cognitive task analyses (CTA).

Cognitive task analysis has been used to train operators of complex systems to develop the cognitive and decision-making skills necessary to manage the complexity of an ensuing crisis (Perkins & Grotzer,1997; Kaempf, Klein, Thordsen, & Wolf, 1996). The goal of CTA is to describe the work environment and cognitive processes requisite to achieving an operator's goal (Zachary, Ryder, & Hicinbothom, 2006).

For example, once specific critical incidents in anesthesia are identified (difficult airway management, pneumothorax, malignant hyperthermia, etc.), faculty could develop hands-on experiences in the simulated operating room that would provide real-time critical decision-making opportunities for GSRNAs while incorporating unpredictable and unfamiliar external events. GSRNAs will be challenged to think critically, re-evaluate priorities as the crisis unfolds, understand the consequences of tentative decisions, and make sense of indirect and ambiguous cues. Such hands-on experiences in a high-fidelity simulated operating room would offer learners a chance to assimilate cognitive processes with key behaviors (Reason, 1990). Throughout the graduate curriculum, GSRNAs could potentially circulate through a series of simulated anesthesia-specific critical incidents, developed through CTA, thereby enhancing their cognitive abilities in this domain.

Another practical implication of the current research relates to nurse anesthesia program admissions processes. Currently, the criteria for admission into a nurse anesthesia program in the US is established by each individual program, but, per the Council on Accreditation of Nurse Anesthesia Educational Programs (COA), must at least include a bachelor's of science in nursing or another appropriate baccalaureate degree, an active license as a registered nurse, and a minimum of one year of acute care (usually ICU) nursing experience. The reason for the longstanding mandate by the COA of one year acute care experience is not well described or documented, but is embraced by nurse anesthesia faculty as a measure of some desirable level of critical thinking and technical aptitude necessary for successful completion of the program.

Despite the acute care experience requirement, some students still fall short of the necessary skills to manage the complexity and uncertainty characteristic of the operating room environment. The findings of this study support this notion in that no significant relationship was found between automaticity, measured in length of time working in the ICU, and SA. Perhaps, the prerequisite one year acute care experience is not as predictive of successful performance in the program as once thought to be.

In the current study, subjects with higher cognitive abilities demonstrated higher levels of SA. The Raven's SPM, an economical, easy-to-administer paper and pencil test of eductive ability, may be entertained and explored by program faculty as a more reliable predictor, when compared to acute care experience, of an applicant's ability to manage complexity, make critical decisions, and solve unfamiliar problems.

Limitations

The limitations of this study relate to the study design, variable measures, and statistical analysis methods. These limitations impact internal and external validity and are acknowledged and addressed in this section.

Threats to Internal Validity

The internal validity of this study is concerned most with accounting for as many factors as possible so that the effects of variables not measured in the study are minimized (Isaac & Michael, 1997).

The use of the Self-Report Data Sheet holds the potential for response bias. Older subjects may have reported less age due to social desirability. Similarly, approximations of length of time working in the ICU may have required less effort to report than actual time. To minimize response bias, subjects were reminded that all responses were confidential and that accurate responses were extremely important to the credibility of the study.

The WOMBAT-CS is a quantitative measure of situation awareness. It has been demonstrated to be a valid measure of situation awareness in the aviation industry (O'Hare, 1997). Validity of the WOMBAT-CS in the population of GSRNAs was assumed in this study after a thorough comparison of operator characteristics and complex working environments between anesthesia and aviation was established from the literature. However, individual differences between pilots and GSRNAs may exist. Future studies empirically validating the WOMBAT-CS in the nurse anesthesia domain are warranted. A study similar to O'Hare's (1997) could be conducted on non-anesthetists vs. novice Certified Registered Nurse Anesthetists (CRNAs) vs. expert CRNAs. If study results were to reveal the highest scores on WOMBAT-CS for expert CRNAs and the lowest scores on WOMBAT-CS for non-anesthetists, predictive validity of the WOMBAT-CS in a population of nurse anesthetists could be considered (Polit & Beck, 2007).

There are no valid and reliable measures of automaticity as operationalized in Endsley's theory that cross all domains. Endsley (2000) suggests that any measure of automaticity should aim to capture highly routine action-selection sequences developed with experience and should be domain specific. Since all GSRNAs are required to have acute care experience and the environment in the ICU has been likened to the environment in the operating room, the researcher justified length of time working as a registered nurse in the ICU as a measure of automaticity.

With no evidence of a relationship between automaticity and SA in this study, it is possible that automaticity is not solely an individual attribute as Endsley suggests. Measures of automaticity may be more valid and reliable if situation specific. For example, there may be a strong relationship between automaticity in the ICU and SA in that same situation-specific environment. In the current study, a significant relationship between automaticity and SA may not have been appreciated because automaticity was measured in the ICU environment and SA was measured in a non-ICU environment. Therefore, more empirical attention directed at defining and developing domain-specific measures of automaticity may add credibility to future work in this area and contribute to a better understanding of Endsley's theory of SA.

The issue of attrition is of concern given that 36 subjects (32%) had no scores on the measure of SA (Polit & Beck, 2007). This may be explained by the fact that some GSRNAs are burdened more than others with very busy schedules due to didactic courses, providing anesthesia in the operating room, pre-operative patient preparation, and family obligations. Also, it is reasonable to expect varying levels of motivation among subjects. Regardless of the reason, it is important to consider that subjects opting to forego the WOMBAT-CS assessment may differ from subjects who completed the assessment. Also, missing scores on the WOMBAT-CS were identified as not missing at random (NMAR) thereby introducing a possibility of selection bias. An attempt was made to mitigate bias by establishing sufficient power with the final sample size.

There are inherent limitations when using multiple regression analysis. At best, regression analysis may reveal associations among variables but do not infer causal relationships. A mild relationship was discovered between memory and SA and a statistically significant relationship was found between cognition and SA. These associations may have been influenced by other variables that were not entered into the analysis. Additionally, the regression solution largely assumes that the variables have been measured without error, which is nearly impossible (Tabachnick & Fidell, 2007).

Statistical transformations to age, memory, and automaticity were necessary to satisfy assumptions of normality, linearity, and homoscedasticity. Although all transformed variables were highly correlated with the measured variables, statistical results using transformed variables may be more difficult to interpret accurately (Tabachnick & Fidell, 2007).

Threats to External Validity

External validity refers to the generalizability of the results or how well the findings represent what is real in an entire population and in other environments (Isaac &

Michael, 1997; Polit & Beck, 2004)). Areas of concern in this study related to external validity include sampling and the effect of the study itself.

A convenience sample of nurse anesthesia programs was chosen for this study. This convenience sample was taken from three nurse anesthesia programs in the southeastern US, and although it may have some regional generalizability, the sample of programs may not be representative of other nurse anesthesia programs in the US. Therefore, in considering the study findings, users of this research may be more confident in generalizing the results to the accessible population, GSRNAs enrolled at Virginia Commonwealth University, Samford University, and Louisiana State University, than to the entire population of GSRNAs. Furthermore, this study was dependent upon subject volunteers. Generalizability of study findings is compromised when volunteers are enrolled because there is a chance that characteristics of the volunteer pool differ from those of non-volunteers.

Consideration should be given to the reactive effects of the study process itself. If it was perceived by study subjects that their performance on any of the measures could negatively or positively affect their status in the nurse anesthesia program, they may have altered their normal behavior for some desired effect. Therefore, it cannot be certain that performance on measures by the study cohort would be replicated by GSRNAs in non-experimental circumstances (Isaac & Michael, 1997). Careful attention was given during the initial information session to assure subjects that their responses and performance related to the study were confidential and would have no impact on their academic standing.

Conclusions and Recommendations for Future Research

This research examined individual predictors of situation awareness in GSRNAs and revealed a mild association between memory and SA (r=.204, p=.088) and a statistically significant relationship between cognition and SA (r=.442, p=.000). After stepwise regression analysis, it was determined that cognition alone best predicts SA in GSRNAs, with the addition of age, gender, memory, and automaticity adding no more predictive value to the model. These findings, given the study limitations, generate questions regarding the development of SA in this population of anesthesia providers.

Human error continues to adversely impact the US health care system. Anesthesia is a specialty within that system known to be unusually susceptible to error and poor patient outcomes. A critical analysis of the most vulnerable processes involved in the delivery of anesthesia should be further considered in light of the work of Reason (1990) and Rasmussen (2003). These plausible theories of error offer considerable explanations for human error in complex systems and when combined with Endsley's theory of SA, have the potential to serve as effective frameworks for examining the role of SA in preventing and managing crises in health care.

Further exploration of the utility of high-fidelity simulated operating rooms in promoting SA and other essential non-technical skills such as decision-making and problem-solving is warranted in the education of GSRNAs. This hands-on applied teaching methodology gives educators opportunities to enhance critical thinking and other domain-specific cognitive skills. Additionally, educators can explore and study elements of successful crisis management, including SA, in an environment that poses no risk to patients. Many nurse anesthesia educational programs house human patient simulators, but do not put them to use in any systematic and meaningful way. This study, examining predictors of SA in GSRNAs, may contribute to the development of an evidence-based approach to using these expensive but effective technologies to support educational outcomes and enhance programmatic goals.

Patient safety is one of the most important markers of quality in health care. A critical precursor to safety is properly trained health care providers who are not only technically competent, but who are also critical thinkers and adept crisis managers. Because crises in anesthesia are rare events, nurse anesthesia educators are challenged with producing graduates able to meet the complex and rapidly-changing demands characteristic of the specialty. Future educational programs of research directed at gaining a better understanding of SA and its role in the provision of safe anesthesia have the potential to make significant contributions to nurse anesthesia training and patient safety.

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VITAE

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